RFP-ENV-88

ROCKY FLATS PLANT SITE ENVIRONMENTAL REPORT FOR 1988

JANUARY THROUGH DECEMBER 1988

Rockwell International

Aerospace Operations
Rocky Flats Plant

PREPARED FOR THE U. S DEPARTMENT OF ENERGY
UNDER CONTRACT DE-AC04-76DP03533

FRACTIONS AND MULTIPLES OF UNITS

Multiple	Decimal Equivalent	Prefix	Symbol
10^{6}	1,000,000	mega-	M
10^{3}	1,000	kilo-	k
10^{2}	100	hecto-	h
10	10	deka-	da
10^{-1}	0 1	deci-	d
10^{-2}	0 01	centi-	c
10^{-3}	0 001	milli-	m
10^{-6}	0 000001	micro-	μ
10^{-9}	0 000000001	nano-	n
10^{-12}	0 000000000001	pico-	p
10^{-15}	0 000000000000001	femto-	f
10^{-18}	0 000000000000000001	atto-	a

CONVERSION TABLE

Multiply	By	Equals	Multiply	By	Equals
in	2.54	cm	cm	0.394	in
ft	0.305	m	m	3.28	ft.
mi	1 61	km	km	0 621	mi
lb	0 4536	kg	kg	2.205	lb
liq qt - U S	0.946	l	l	1 057	liq qt - U S
ft^2	0 093	m^2	m^2	10 764	ft^2
mi^2	2.59	km^2	km^2	0.386	mi^2
ft^3	0 028	m^3	m^3	35.31	ft^3
d/m	0 450	pCi	pCi	2.22	d/m
pCi/l (water)	10^{-9}	μCi/ml (water)	μCi/ml (water)	10^{9}	pCi/l (water)
pCi/m^3 (air)	10^{-12}	μCi/cc (air)	μCi/cc (air)	10^{12}	pCi/m^3 (air)

Printed
May, 1989

RFP-ENV-88

ROCKY FLATS PLANT SITE ENVIRONMENTAL REPORT FOR 1988

January through December 1988

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Rockwell International

Aerospace Operations
Rocky Flats Plant

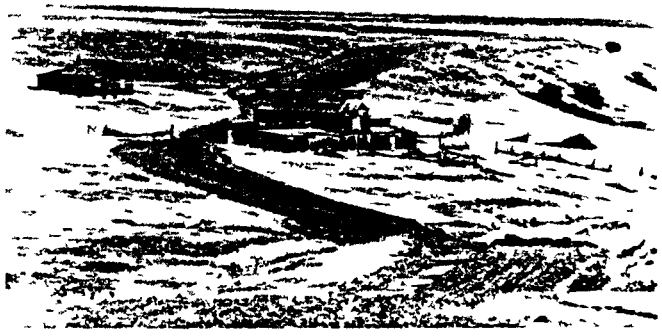
Prepared under Contract DE-AC04-76DP03533
for the Albuquerque Operations Office
U S Department of Energy

3

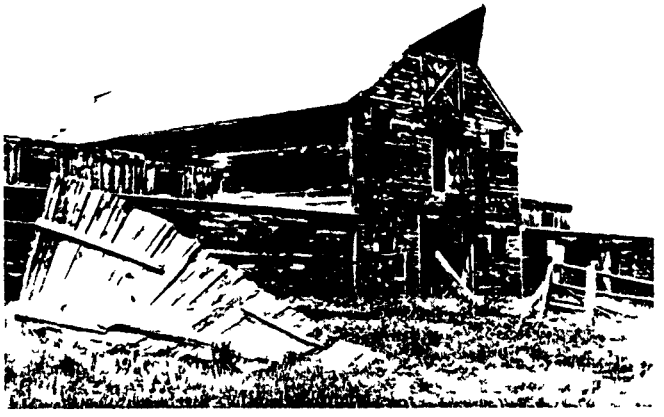
These are a few scenes from the Rocky Flats Plant

Rocky Flats Plant Buffer Zone in the Spring

Rocky Flats Plant Wildlife found
in the Buffer Zone



Lyndsey Ranch located in Rocky
Flats Plant Buffer Zone



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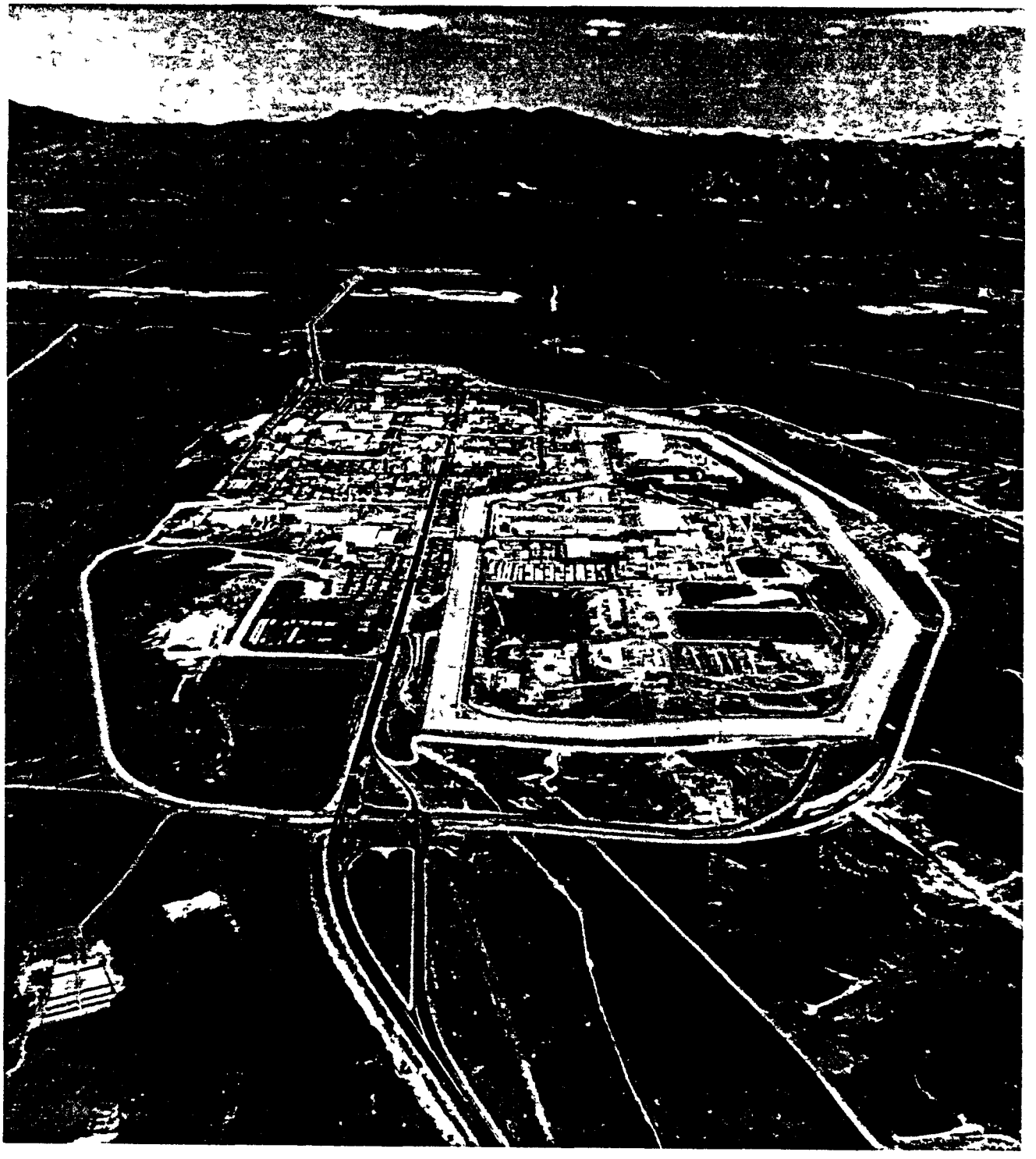

ROCKY FLATS PLANT VIEWED FROM THE EAST

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

10

ACKNOWLEDGEMENTS

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W S Busby
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B R Lewis
A M Long
C L Sundblad

The authors are indebted to the following individuals who were instrumental in the preparation and review of this report

J A Blair
D L Bokowski
C S Darson
S P Deutch
R B Falk
G Hansen
M W Hume
J M Johnson
J M Langsted
K Motyl
B R Rognlie
M R Salasky
C Trice
N Wilkinson

Special thanks to the following groups for their hard work and dedication

General Laboratories
Illustrations
HS&E Laboratories
Printing
Photography

ABBREVIATIONS AND ACRONYMS

Am	Americium
Be	Beryllium
BOD_5	Biochemical Oxygen Demand, 5 day incubation period
Bq	Becquerel
Bq/l	Becquerels per liter
Bq/m^3	Becquerels per cubic meter
CDH	Colorado Department of Health
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Ckg-1	Coulombs per kilogram
Cm	Curium
CO	Carbon monoxide
CY	Calendar year
DCG	Derived Concentration Guide
d/m/f	Disintegrations per minute per filter
d/m/l	Disintegrations per minute per liter
DOE	(United States) Department of Energy
dpm	Disintegrations per minute
dps	Disintegrations per second
EM	Environmental Management
EML	(DOE) Environmental Measurements Laboratory
EPA	Environmental Protection Agency
ft^3/min	Cubic feet per minute
HEPA	High efficiency particulate air (filter)
HS&E	Health, Safety and Environment
HS&E Labs	Health, Safety and Environment Laboratories
H-3	Hydrogen-3 (also called "tritium")
ICP	Inductively coupled plasma
Jkg-1	Joules per kilogram
l/s	Liters per second
MDA	Minimum detectable amount
MDC	Minimum detectable concentration
mg/l	Milligrams per liter
mg/m^3	Milligrams per cubic meter
ml	Milliliter
mrem	Millirem
m/s	Meters per second
N	Nitrogen
NA	Not Applicable
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NO_2	Nitrogen dioxide
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission

12

ABBREVIATIONS AND ACRONYMS

OAHP	(State of Colorado) Office of Archaeology and Historic Preservation
O_3	Ozone
Pb	Lead
pCi	Picocurie
pCi/g	Picocuries per gram
pCi/l	Picocuries per liter
ppb	Parts per billion
ppm	Parts per million
PCE	Tetrachloroethylene
PM-10	Particulate matter, 10 micrometers or less in diameter
Pu	Plutonium
RCRA	Resource Conservation and Recovery Act
rem	Roentgen equivalent man
RFP	Rocky Flats Plant
RI	Rockwell International
SAAM	Selective alpha air monitor
SO_2	Sulfur dioxide
STP	Sewage Treatment Plant
SU	Standard Unit
Sv	Sievert
TCE	Trichloroethylene
TLD	Thermoluminescent dosimeter
TLLα	Total long lived alpha
Tm	Thulium
TSP	Total suspended particulates
U	Uranium
VOC	Volatile organic compound
μCi	Microcurie
μCi/ml	Microcuries per milliliter
μg/f	Micrograms per filter
$\mu g/m^3$	Micrograms per cubic meter

ABSTRACT

This report documents the 1988 environmental surveillance program at the Rocky Flats Plant The program is conducted by the Environmental Management Section of the Health, Safety and Environment (HS&E) Department under the operating contractor, Rockwell International, Aerospace Operations Group Sample analyses are performed by the Health, Safety and Environmental Laboratories (HS&E Labs) of HS&E and by the General Laboratory of the Quality Engineering and Control Department The report includes an evaluation of plant compliance with all appropriate guides, environmental limits, and standards Potential radiation dose to the public was calculated from average radionuclide concentrations measured at the plant property boundary and in surrounding communities The radioactive effluents from the Rocky Flats Plant meet the appropriate guides and standards and represent no measurable adverse environmental effects from the operation of the plant during calendar year 1988 The estimated potential radiation doses to the public from plant effluents are below Department of Energy and Environmental Protection Agency dose limits and are well below background dose levels experienced in the region from natural and other non-Rocky Flats Plant sources

14

1
INTRODUCTION

The Rocky Flats Plant is a government-owned and contractor-operated facility It is part of a nationwide nuclear weapons research, development, and production complex administered by the Albuquerque Operations Office of the U S Department of Energy (DOE) The prime operating contractor for the Rocky Flats Plant is the Aerospace Operations Group of Rockwell International

The Rocky Flats Plant is located at 105° 11'30" west longitude and 39° 53'30" north latitude in northern Jefferson County, Colorado The plantsite consists of 2,650 hectares (6,550 acres) of federally owned land As shown in Figure 1, major plant structures are located within a security-fenced area of 155 hectares (384 acres) The plant is approximately 26 kilometers (16 miles) northwest of downtown Denver and is almost equidistant from the cities of Boulder, Golden, and Arvada (see Figure 2) Demographic estimates for 1988 are shown in Figure 3 There is a population of approximately 2 million people within a 50-mile radius of the plant

The plant is a key DOE facility that produces components for nuclear weapons, therefore, its product is directly related to national defense The plant is involved in fabricating components from plutonium, uranium, beryllium, and stainless steel Production activities include metal fabrication and assembly, chemical recovery and purification of process-produced transuranic radionuclides, and related quality control functions Research and engineering programs supporting these activities involve chemistry, physics, materials technology, ecology, nuclear safety, and mechanical engineering

The piedmont of the Front Range of the Rocky Mountains rises 8 kilometers (5 miles) west of the site and crests at the Continental Divide, which is 32 kilometers (20 miles) from the plant The natural environment of the plantsite and vicinity is influenced primarily by the Front Range of the Rocky Mountains and the site elevation, which is 1,829 meters (6,000 feet) above sea level The surficial geology of Rocky Flats consists of a thin layer of gravelly, fine-textured topsoil underlain by a 6- to 15-meter (20- to 49-foot) thick layer of coarser, clayey gravel This is underlain by a bedrock structure upon which plant building foundations are supported Area hydrology is influenced by the surficial materials, which consist of gravelly but slowly permeable alluvium The vegetation of the area consists of species representative of the short- and mid-grass prairie, primarily grasses, cacti and broom snakeweed Introduced Eurasian weeds also make up part of the flora, and riparian vegetation exists along the watercourses

The climate at Rocky Flats is characterized by dry, cool winters with some snow cover and warm summers There is considerable clear-sky sunshine, and both the average precipitation and relative humidity are low The elevation of the plant and the major topographical features of the area significantly influence the climate and meteorological dispersion characteristics of the site Winds at Rocky Flats, although variable, are predominantly northwesterly, with stronger winds occurring during the winter

1. Introduction

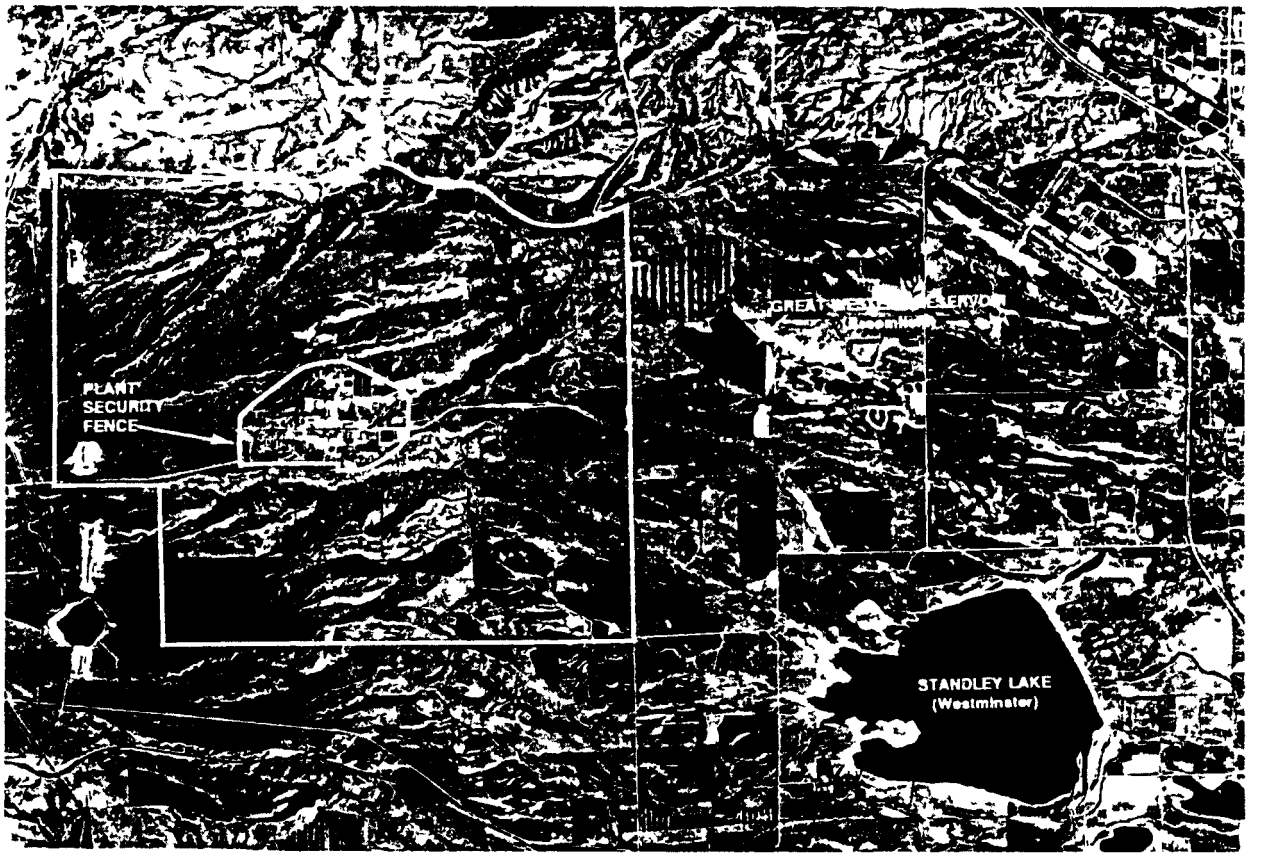


FIGURE 1 Aerial Photograph of the Rocky Flats Plant and Immediate Vicinity

The maximum annual precipitation recorded over a 24-year period was 63 17 centimeters (24 87 inches) in 1969 Typically, more than 80 percent of the precipitation falls as rain between April and September Most of the remaining precipitation is in the form of snow

Land use at the Rocky Flats Plant is managed by Rockwell International for the Department of Energy This includes land utilization planning and environmental and physical control of the land Since 1977, all major activities conducted on plantsite land require approval by the Rockwell Executive Land Use Committee based upon the recommendations of the Land Use Coordinator The Coordinator evaluates all research projects and other nonroutine activities on plant lands by means of a Land Use Request system The effects of such activities are evaluated by Environmental Management personnel through field observations

Approximately 140 structures on the plantsite contain approximately 256,400 square meters (2 76 million square feet) of floor space Of this space, major manufacturing, chemical processing, plutonium recovery, and waste treatment facilities occupy about 148,600 square meters (1 6 million square feet)

The remaining floor space is divided among laboratory, administrative, utility, security, warehouse, storage, and construction contractor facilities, and occu-

pies about 107,800 square meters (1 16 million square feet)

The primary plant heating requirements are met by in-plant steam boilers that normally use natural gas but are capable also of using fuel oil In addition, small amounts of liquified petroleum gas and electricity are used for some heating at the plant During CY 1988, approximately 19 3 million cubic meters (680 million cubic feet) of natural gas were used No fuel oil was used during 1988

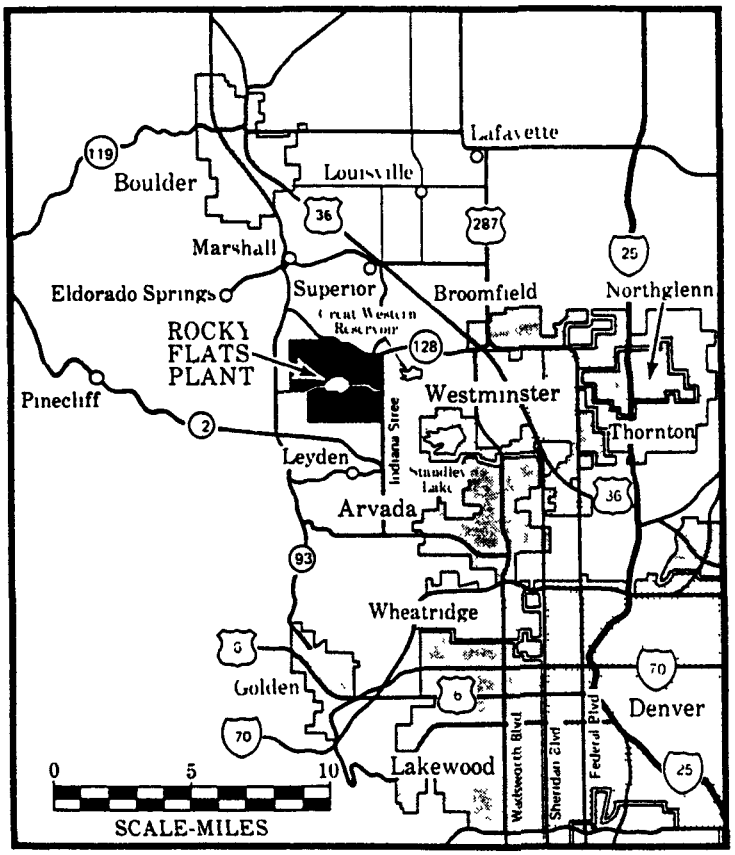


FIGURE 2 Area Map of Rocky Flats Plant and Surrounding Communities

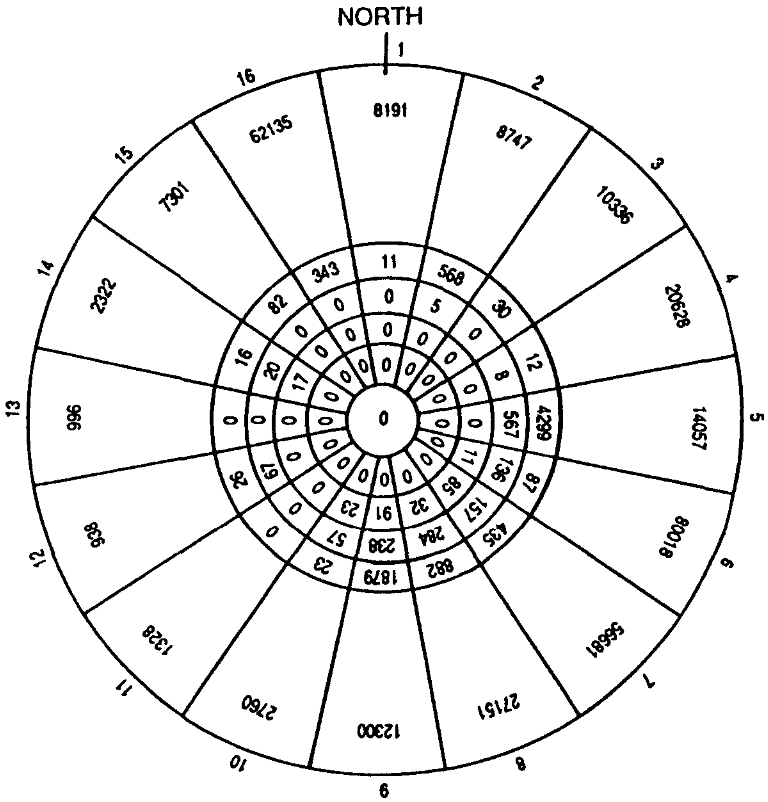
Raw water is purchased from the Denver Water Board and is drawn from Ralston Reservoir and the South Boulder Diversion Canal The Rocky Flats Plant used approximately 507 million liters (134 million gallons) of water during 1988

Certain operations at the Rocky Flats Plant involve or produce liquids, solids, and gases containing radioactive materials Radioactive materials are handled in accordance with stringent procedures and within multiple containments (physical barriers) designed to minimize the release of contaminants to the workplace and the environment Processing activities include the incineration of plutonium-contaminated materials for recovery of the plutonium that they contain This recovery operation is conducted in accordance with an incineration permit issued to the plant by the Colorado Department of Health

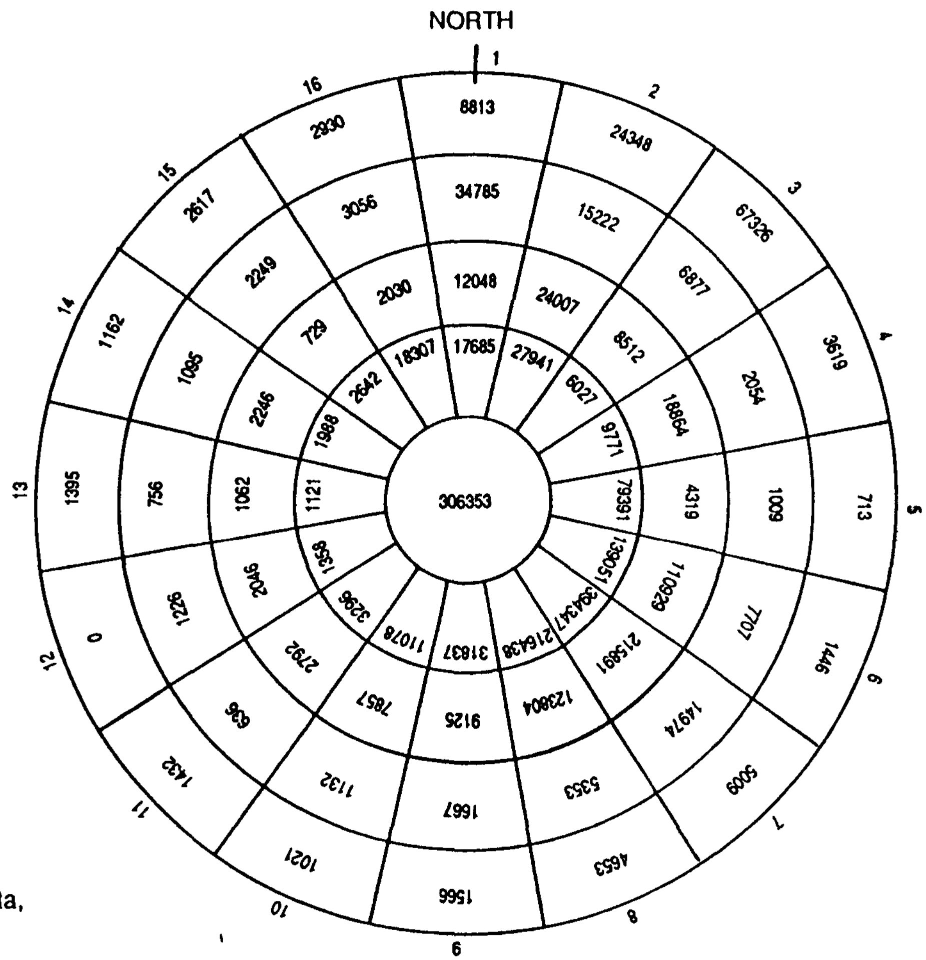
Air from production and research facilities is continuously discharged to the atmosphere by 50 ventilation exhaust systems Prior to atmospheric discharge, the exhaust air passes through particulate filtration systems located in filter plenums These filtration systems employ High Efficiency Particulate Air (HEPA) filters that are purchased to equal or exceed the DOE specified filtration efficiency standard of 99 97 percent for 0 3 micrometer particles Prior to installation in the filter plenum, each filter is tested at the plant to ensure that the filtration efficiency is not less than the standard Once installed, filters are tested for leaks which might have developed during handling and installation Any deficiencies are corrected and the system retested Airborne effluents for all

(7

FIGURE 3 1988 Demographic Estimates[a]



0 TO 60 km (0 to 10 miles) FROM ROCKY FLATS[b]



16 TO 80 km (10 to 50 miles) FROM ROCKY FLATS[c]

a These population estimates were calculated from 1980 census tract data, assuming uniform population distribution throughout each section

b Concentric circles represent 1 6 to 3 2-, 3 2- to 4 8-, 4 8- to 8 0-, 8 0- to 16 0-km (1- to 2-, 2- to 3-, 3- to 4-, 4- to 5-, and 5- to 10-mi) bands

c Concentric circles represent 16 to 32-, 32- to 48-, 48- to 64-, 64- to 80- km (0 to 20-, 20- to 30-, 30- to 40 , 40- to 50- mi) bands

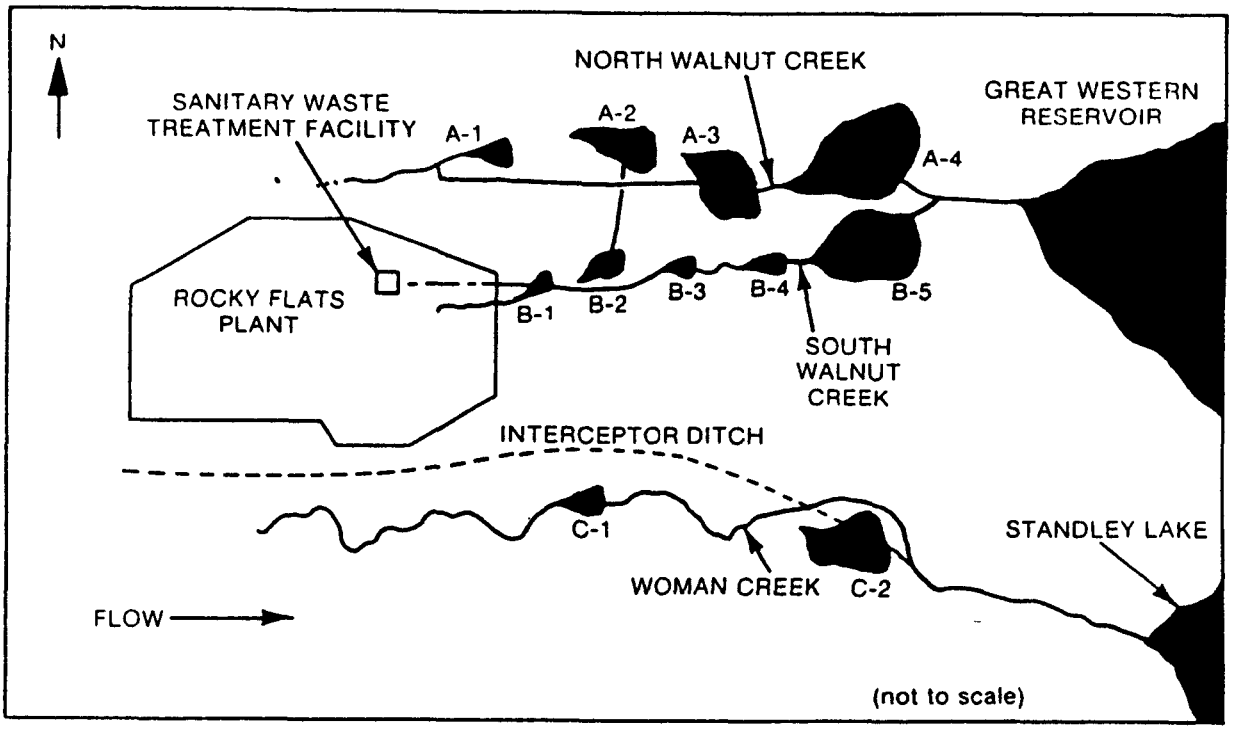


FIGURE 4 Holding Ponds and Liquid Effluent Watercourses

plant processing buildings are continuously monitored for radioactive emissions Airborne radioactivity released to the environment from process operations is kept to a minimum and is well within plant health and safety guidelines

The radioactive waste systems include collection, filtration, liquid processing, and temporary storage facilities for those process wastes known, or suspected, to have been in contact with radioactive materials The liquid waste process system concentrates the contamination from liquid waste into solid wastes suitable for shipment, along with other contaminated solid wastes, to a DOE-approved storage or disposal facility Specific details of plant waste processing facilities are described in the Rocky Flats Plant Site Final Environmental Impact Statement (US80a)

Sanitary waste is processed by the sanitary wastewater treatment plant, and is isolated from process waste throughout the plant Conditioning chemicals are added to improve flocculation and filtration of suspended solids The treatment plant is of the activated sludge type and has three stages of treatment It has a design capacity of 1 9 million liters (500,000 gallons) per day Present daily flows usually vary between 757,000 and 1 1 million liters (200,000 and 300,000 gallons) per day One of two 227,000-liter (60,000 gallon) preaeration holding tanks, located upstream from the sewage plant, serves as a surge basin to smooth out peak flows A second holding tank provides storage capacity for sanitary wastes should emergency retention be required Liquid effluents from the sanitary waste treatment plant are released to holding ponds for subsequent onsite irrigation or off-

1. Introduction

site discharge to Walnut Creek The plant has a zero discharge goal with respect to downstream discharges Such discharges occur only when weather conditions prevent effective spray irrigation activities as stipulated by the plant Environmental Protection Agency National Pollutant Discharge Elimination System (NPDES) Permit All surface water discharges are conducted in accordance with the NPDES permit. Residual solids from the sanitary waste treatment plant are concentrated, dried, packaged, and shipped to a DOE-approved waste facility

In 1988, solid wastes that had no radioactive or hazardous chemical constituents were transferred to an onsite sanitary landfill for disposal This landfill was designed and constructed in 1974 with an impervious clay seal layer, a ground water intercept system, and surface water diversion ditches to isolate the landfill from the general environment Routine waste materials are checked daily for radioactivity at the landfill site before final burial In addition, routine waste materials originating from buildings in which radioactive materials are handled are monitored prior to leaving the building to ensure that they are free from radioactive contamination The disposal of nonroutine or special non-radioactive waste materials is administratively controlled

Ground water and surface water flow in and around the sanitary landfill is controlled by interceptor ditches and by french drains The ditches divert all upgradient surface waters around the landfill The drains collect ground water from the perimeter of the landfill and divert it around the landfill A holding pond collects surface and subsurface drainage from the landfill Water samples from this holding pond, the drains, and from twenty-one (as of 1988) RCRA-quality ground water monitoring wells in the vicinity are collected routinely and are analyzed for a series of parameters including radioactivity

As shown in Figure 4, surface water runoff from the plant generally is from west to east Runoff is carried from the plant by three major drainage basins that are tributaries to Walnut Creek on the north and to Woman Creek on the south The south fork of Walnut Creek receives most of the stormwater runoff from areas surrounding plant buildings

Also shown in Figures 1 and 4 is the confluence of the north and south forks of Walnut Creek which is 1 1 kilometers (0 7 miles) west of the eastern perimeter of the plant Great Western Reservoir, a water supply for a part of the City of Broomfield, is 1 6 kilometers (1 mile) east of this confluence Woman Creek flows east from Rocky Flats into Standley Lake, a water supply for the City of Westminster and for portions of the cities of Northglenn and Thornton Ponds on the north fork of Walnut Creek are designated A-1 through A-4 Ponds on the south fork are designated B-1 through B-5 These A- and B-series ponds receive precipitation runoff and/or treated sanitary wastewater Pond C-1 is located on the Woman Creek watercourse and receives only undisturbed natural flows Pond C-2, located near the Woman Creek watercourse, receives surface runoff water from an interceptor ditch parallel to the south side of the plant production areas

Personnel in the Environmental Management Group of Rockwell International conduct an extensive envi-

ronmental control and surveillance program at the plant Engineering reviews of proposed plant projects are performed to ensure that appropriate safeguards are taken for environmental protection The environmental surveillance program is designed to provide assurance that these safeguards effectively limit the release of radioactive or toxic materials

The Rocky Flats Plant environment is monitored for penetrating ionizing radiation and for pertinent radioactive, chemical, and biological pollutants Air, water, and soil are sampled on the plantsite and throughout the surrounding region Several Federal, State, and local governmental agencies independently conduct audits and additional environmental surveys both on and off the plantsite The Colorado Department of Health samples air, soil, and water at the Rocky Flats site and in surrounding communities The DOE Environmental Measurements Laboratory (EML) historically has conducted particulate air sampling at the Rocky Flats Plant and has periodically performed special studies, including sediment and soil analyses Additional special analyses have been performed by Region VIII of the U S Environmental Protection Agency (EPA) The City of Broomfield monitors water quality in Walnut Creek and Great Western Reservoir, and in November, 1988, the City of Westminster initiated a monitoring program for Standley Lake Data from the Rocky Flats Plant, the Colorado Department of Health, and the cities of Broomfield and Westminster are reported monthly at an Environmental Monitoring Information Exchange Meeting that is open to the public Also identified at this meeting are the radioactive materials used or handled at the plant and plant engineering projects which may have an environmental interest This monthly environmental information exchange meeting has been ongoing since the early 1970's

The information contained in this report is submitted in compliance with DOE Orders 5484 1 Chapters III and IV, and 5400 1 Chapter II, and is a compilation of data provided monthly to the DOE Rocky Flats Area Office, the Radiation Control Division of the Colorado Department of Health, EPA Region VIII, the health departments of Boulder and Jefferson Counties, and to interested city officials and citizens from communities near the plant

2
SITE METEOROLOGY AND CLIMATOLOGY

Meteorological data were collected on the plantsite from instrumentation installed on a 61-meter (200-foot) tower located in the west buffer zone during 1988 Meteorological information in this report represents 75 percent data recovery from this instrumentation Table 1 is the 1988 annual summary of the percent frequency of wind directions (16 compass points) divided into four wind speed categories The compass point designations indicate the true bearing when facing against the wind These frequency values are represented graphically in Figure 5 The wind rose vectors also represent the bearing against the wind (i e , wind along each vector blows toward the center) The predominance of northwesterly winds is typical of Rocky Flats The low frequency of winds greater than 7 meters per second (15 6 mph) with easterly components is normal

The mean temperature recorded for 1988 was 8 6 °C (47.5 °F) In 1988, the Rocky Flats Plant recorded 32 18 centimeters (12 67 inches) of precipitation

Based on 24-year monthly water-equivalent precipitation averages collected between 1953 and 1976, the mean annual precipitation at Rocky Flats is 38 50 centimeters (15 16 inches)

TABLE 1 Wind Direction Frequency (Percent), by Four Wind-Speed Classes, at the Rocky Flats Plant

(Fifteen-Minute Averages — 1988)

Wind Direction	Calm	1-3 (m/s)	3-7 (m/s)	7-15 (m/s)	>15 (m/s)	TOTAL
-	9 25	-	-	-	-	9 25
N	-	1 25	1 57	0 55	0 00	3 37
NNE	-	1 94	1 10	0 13	0 00	3 17
NE	-	1 80	0 47	0 00	0 00	2 27
ENE	-	2 09	0 13	0 01	0 00	2 23
E	-	3 07	0 61	0 01	0 00	3 69
ESE	-	3 46	1 81	0 07	0 00	5 34
SE	-	3 55	2 37	0 21	0 00	6 13
SSE	-	2 92	2 46	0 27	0 00	5 65
S	-	3 44	2 79	0 34	0 00	6 57
SSW	-	3 37	2 35	0 30	0 00	6 02
SW	-	2 97	3 98	0 49	0 00	7 44
WSW	-	3 06	3 06	0 71	0 04	6 87
W	-	3 39	2 87	2 96	0 72	9 94
WNW	-	3 03	4 42	2 79	0 12	10 36
NW	-	3 13	3 44	0 59	0 00	7 16
NNW	-	1 77	2 32	0 45	0 00	4 54
TOTAL	9 25	44 24	35 75	9 88	0 88	100 00

FIGURE 5 1988 Annual Wind Rose for the Rocky Flats Plant

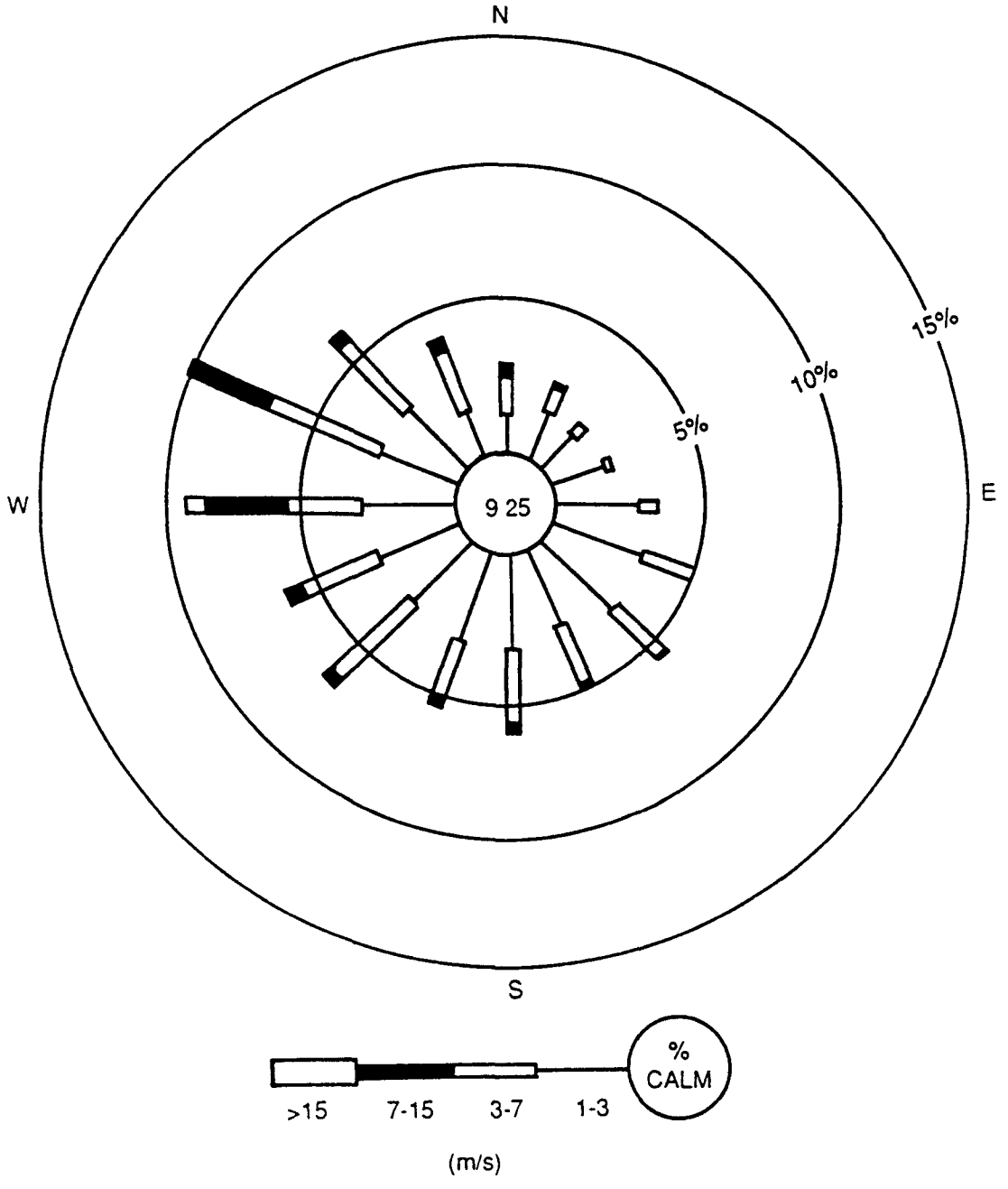
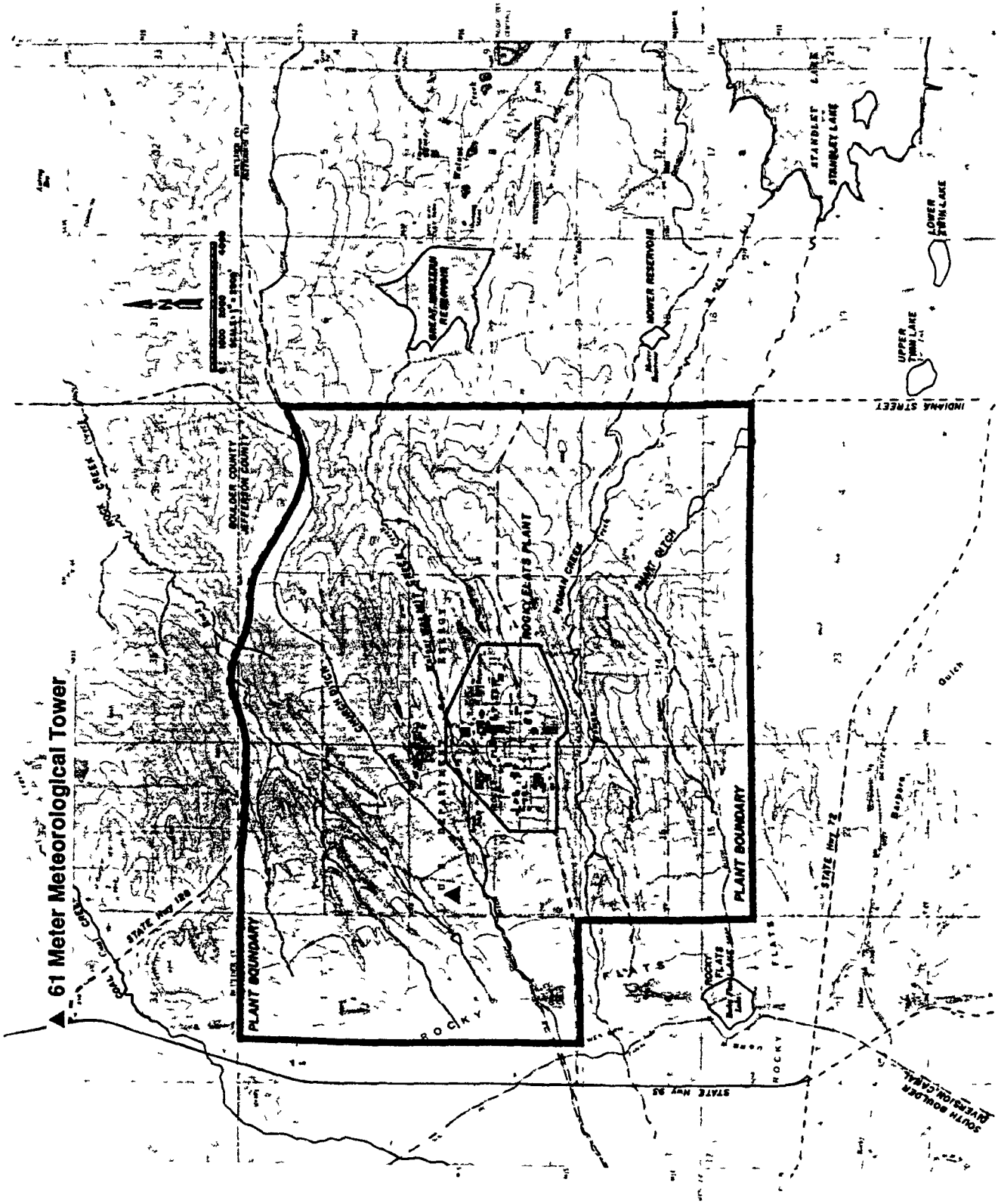


FIGURE 6 Location of Rocky Flats Plant 61 Meter Meteorological Tower



3
PERMITTING ACTIVITIES

Several environmental permits have been issued to the plant by Federal and State agencies Currently, the following permits are in "Active" status

National Pollutant Discharge Elimination System Permit CO-0001333, issued by the U S Environmental Protection Agency, December 26, 1984

Building 122 Incinerator Permit C-12, 931, issued by the Colorado Department of Health, March 25, 1982

Building 771 Incinerator Permit 12JE932 (C-12, 932), issued by the Colorado Department of Health, August 28, 1985

Building 776 Fluid Bed Incinerator Permit C-13, 022, issued by the Colorado Department of Health, March 25, 1982

Fugitive Dust Emission Permit 87JE052L for offsite soil remedial action program, issued by the Colorado Department of Health on June 15, 1988

On July 31, 1986, a Compliance Agreement was entered into by the Environmental Protection Agency (EPA), the Colorado Department of Health (CDH), and the Department of Energy (DOE) for implementation and regulation of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) activities for the Rocky Flats Plant On November 26, 1986, the Rocky Flats Plant submitted a RCRA Part B Permit Application to EPA and CDH The RCRA Part B Permit Application was revised in accordance with comments received from EPA and CDH and re-submitted on December 15, 1987 A Notice of Completeness for the Part B Application was received in August, 1988 A separate Part B Permit Application was submitted for transuranic mixed waste in June, 1988 The submittal of draft Remedial Investigation reports on July 1 and December 31, 1987, also took place in accordance with the Compliance Agreement A revised Remedial Investigation Report with a Feasibility Study on the 881 Hillside was submitted to EPA and CDH on March 1, 1988 The remedial action for the 881 Hillside is expected to begin in 1989

In 1988, no environmental assessments or environmental impact statements were published for the Rocky Flats Plant under the National Environmental Policy Act (NEPA)

A survey for archaeological and historic resources was completed during the summer of 1988 The survey was conducted as required by the National Historic Preservation Act in accordance with established procedures of the State of Colorado Office of Archaeology and Historic Preservation (OAHP) Ten sites of archeologi-

3. Permitting Activities

cal interest were discovered and these known sites were revisited The OAHP has determined that no sites are eligible for nomination to the National Register of Historic Places Two sites received conditions in the OAHP findings correspondence letter requiring further investigation if they are ever to be disturbed Both sites are remote from the developed portion of the facility and will be protected

Photographs taken on Rocky Flats Plant property during the 1988 archaeological survey

Stone Structure used as Barn on Woman Creek

Apple Orchard near 19th Century General Store

4
MONITORING SUMMARY

During 1988, the Rocky Flats Plant conducted an environmental monitoring program that included the sampling and analysis of airborne effluents, ambient air, surface and ground water, and soil External penetrating gamma radiation exposures were also measured using thermoluminescent dosimeters The monitoring program consists of collecting samples from onsite, boundary, and offsite locations Monitoring of water for trace quantities of chemicals, metals, nitrates, anions, volatile organic compounds (VOCs), and specific radionuclides also was performed

Plutonium concentrations in this report represent the alpha radioactivity from plutonium isotopes -239 and -240, which constitute over 97 percent of the alpha radioactivity in plutonium handled at the plant Reported uranium concentrations are the cumulative alpha activity from uranium-233, -234, and -238 Components containing enriched uranium are handled at the Rocky Flats Plant Depleted uranium metal is fabricated and also is handled as process waste material Uranium-235 is the major isotope by weight (93 percent) in enriched uranium, however, uranium-234 accounts for approximately 97 percent of the alpha activity of fully enriched uranium In depleted uranium, the combined alpha activity from uranium-234 and -238 accounts for approximately 99 percent of the total alpha activity

A. Effluent and Ambient Monitoring

Particulate and tritium sampling of building exhaust systems was conducted continuously in 1988 The particulate samples were analyzed for specific radionuclides of interest and for beryllium Overall, 1988 emission data were in the ranges projected in the Plant Environmental Impact Statement (US80a) and represent a negligible environmental impact

Particulate samples are collected by ambient air samplers operated continuously onsite near the plant building areas, at the plant perimeter, and in fourteen community locations Analysis of these samples indicated that the concentrations of airborne plutonium at all locations were far below applicable Derived Concentration Guides (DCGs) (See Appendix A for a discussion of the calculation of DCGs) At the plant perimeter and at the community locations, the 1988 average plutonium concentrations in ambient air at each location were 0 05 percent or less of the DOE DCGs

During 1988 monitoring of ambient air for non-radiological total suspended particulates (TSP) and respirable particulates (PM-10), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen diox-

ide (NO_2), and lead (Pb) was conducted These six parameters are criteria pollutants regulated on a regional basis by the EPA and the State of Colorado through the Clean Air Act of 1970 that includes the National Ambient Air Quality Standards (NAAQS) (US81b) The 1988 calculated annual geometric mean for TSP was 53 percent of the former primary annual geometric mean standard prescribed by the NAAQS Respirable particulates measured by the new PM-10 methodology indicated values that were 31 percent of the annual arithmetic mean primary standard of 50 mg/m^3 The highest one-hour concentration of O_3 in 1988 was 75 percent of the EPA primary one-hour standard This value was consistent with trend levels reported in the Denver Metropolitan area at that time (CO88) The 1988 annual arithmetic mean for SO_2 was ten percent of the EPA primary annual arithmetic mean standard The highest recorded one-hour SO_2 reading was 0 021 ppm The maximum one-hour concentration recorded for CO was 5 00 ppm This was 14 percent of the primary one-hour NAAQS of 35 ppm The annual arithmetic mean of the NO_2 concentrations for 1988 was ten percent of the EPA primary annual arithmetic mean standard The quarterly Pb concentrations measured during 1988 were less than two percent of the EPA quarterly standard Since a sufficient, multi-year baseline database for Criteria Pollutants has now been developed for the plant, this nonradioactive ambient air monitoring program is being discontinued effective with this report

Water used during 1988 for plant process operations was evaporated and the condensate reused for cooling tower makeup or steam plant use Sanitary water was treated and spray irrigated within plant boundaries or discharged offsite after monitoring, in compliance with the Rocky Flats Plant Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) Permit (US84a) Surface runoff from precipitation is collected in surface water control ponds After monitoring, this water is discharged offsite Those discharges are monitored for compliance with the EPA NPDES permit During 1988, NPDES BOD_5 limits were exceeded during February, March, April and May and fecal coliform limits were exceeded in April A discussion of these violations appears in Section 5

Routine water monitoring is conducted for two downstream reservoirs and for drinking water sources in nine communities The average radioactivity concentrations for plutonium, uranium, americium, and tritium measured at these locations were found to be 0 4 percent or less of the DCGs for water The sum of the average concentrations for plutonium and americium in drinking water samples for each community was 0 3 percent or less of the State of Colorado regulations for alpha-emitting radionuclides (CO81) and the EPA National Interim Primary Drinking Water Regulations (US76a) Average concentrations of tritium in community drinking water samples were all within local background range and were less than one percent of the applicable State of Colorado and EPA drinking water standards (CO81,US76a)

A vegetation control program using chemical herbicides was conducted during 1988 The program was completed by independent licensed contractors using EPA and the State of Colorado approved chemicals according to the label requirements and DOE Orders Onsite storage of pesticides and herbicides at the Rocky

Flats Plant currently is being discontinued All pesticides used in or near surface waters are approved by EPA for such use

Surface soil samples for plutonium analysis were collected in 1988 from 40 sites located on radii from the Rocky Flats Plant at distances of 1 6 and 3 2 kilometers (1 and 2 miles) The purpose of the program was to determine if there are any changes in plutonium concentrations in the soil around the plant over time This program was conducted intermittently until 1977 and reinitiated during 1984 The 1988 plutonium concentrations in the 3 2 kilometer samples, which are near the plant boundary, were in the range from 0 02 to 7 12 pCi/g (0 74 to 263 Bq/kg) Plutonium concentrations for 1988 at a 1 6 kilometer radius ranged from 0 02 to 10 6 pCi/g (0 74 to 391 Bq/kg) These levels are similar to the soil data reported in 1977 and 1987

The 1988 environmental measurement of external penetrating gamma radiation, using thermoluminescent dosimeters (TLDs), showed that the annual dose equivalent from penetrating radiation onsite, at the plant perimeter, and at community locations, was within the range of regional background

B. Environmental Restoration

As part of the Rocky Flats RCRA/CERCLA Compliance Agreement signed July 31, 1986, extensive hydrologic, geologic, and ground water quality investigations continued through 1988 Initial investigations indicate above background concentrations of some radioactive and chemically hazardous materials within close proximity to past plant disposal sites and plant operations areas These materials include volatile organic compounds (i e , chlorinated hydrocarbon solvents) and some radionuclides

Remedial Investigation activities, an outgrowth of the Compliance Agreement, required the completion of 46 additional monitoring wells during 1987 No additional wells were constructed during 1988, but a number are planned for 1989 construction These new wells will assist in the delineation of radioactive or hazardous chemical constituents in designated high priority investigation areas, and they become part of an extensive plantwide ground water monitoring system Corrective action measures for areas requiring such measures are now under evaluation Monitoring wells also were installed near previously-used solar evaporation ponds and the present landfill as part of the RCRA Closure Permit A total of 159 onsite ground water monitoring wells are now monitored quarterly

C. Public Dose Assessment

Potential public radiation dose commitments, which could have resulted from plant operations, were calculated from average radionuclide concentrations measured at the Rocky Flats Plant property boundaries and in surrounding communities Dose assessment for 1988 was conducted for the property (site) boundary, nearby communities, and to a distance of 80 kilometers

(50 miles) At the plant boundary, the maximum 50-year dose commitment to an individual was calculated to be 7 5 X 10^{-4} rem (7.5 X 10^{-6} Sv) effective dose equivalent and 1 2 X 10^{-2} rem (1 2 X 10^{-4} Sv) to bone surfaces By comparison, annual effective dose equivalent from the natural radiation in the Denver area currently is estimated as about 3 5 X 10^{-1} rem (3.5 X 10^{-3} Sv) (NA87) The 50-year dose commitment of 7 5 X 10^{-4} rem represents less than 1 percent of the DOE interim radiation protection standard of 0 1 rem effective dose equivalent for all pathways If all the dose were received from the air pathway, the bone surfaces dose of 1 2 X 10^{-2} rem would represent 16 percent of the air pathway standard for any organ (VA85)

The maximum radiation dose for community locations was calculated as a 50-year dose commitment of 2 9 X 10^{5} rem (2 9 X 10^{-7} Sv) effective dose equivalent and 5 2 X 10^{-4} rem (5 2 X 10^{-6} Sv) to bone surfaces These values represent 0 03 percent of the DOE interim standard for effective dose equivalent and 0 69 percent of the standard for any organ from the air pathway only (VA85) These values include contributions from residual fallout caused by past global atmospheric weapons testing

The 50-year committed effective dose equivalent to the population living within 80 kilometers (50 miles) of the plant was based on the maximum community dose estimates For the community, the maximum effective dose equivalent was less than the 1 X 10^{-3} rem dose equivalent specified by DOE as *de minimis* (inconsequential) (US80b) The dose commitment for all individuals to a distance of 80 kilometers was, therefore, considered to be *de minimis*

In demonstration of compliance with the EPA Clean Air Act air emissions standard in 40 CFR 61, Subpart H, the AIRDOS-EPA computer code was used to calculate radiation dose to the public by atmospheric dispersion, deposition, and ecological modeling of 1988 air emissions data (US85, VA85) The results of this calculation independently confirm that the maximum radiation dose to a member of the public as a result of exposure to airborne radioactivity from the Rocky Flats Plant in 1988 was less than 1 mrem effective dose equivalent

5
MONITORING DATA

This section describes Rockwell International's environmental monitoring program for 1988, results of sample analyses, and evaluation of the data with regard to applicable guides and standards The reader is directed to the appendixes at the end of this report for detailed information concerning applicable guides and standards, quality control, analytical procedures, detection limits, error term propagation, and reporting of minimum detectable concentrations Appendix E includes a discussion of the methodology used for reporting measurements that were at or below the minimum detectable concentrations (MDC) This appendix also discusses the use of the less-than sign (<) and defines the use of plus or minus (±) error terms in the data

A. Airborne Effluent Monitoring

In 1988 production and research facilities at the Rocky Flats Plant were equipped with 50 ventilation exhaust systems Particulates generated by production and research activities are entrained in the exhaust air streams These particulate materials are removed from the air stream in each exhaust system by means of High Efficiency Particulate Air (HEPA) filters Residual particulates in each of these systems are continuously sampled downstream from the final stage of HEPA filters Ventilation systems that service areas containing plutonium are equipped with Selective Alpha Air Monitors (SAAMs) for immediate detection of abnormal conditions These SAAMs are sensitive to specific alpha particle energies and are set to detect plutonium-239 and -240 These detectors are tested and calibrated routinely to maintain sensitivity The monitors alarm automatically if out-of-tolerance conditions are experienced No such condition occurred during 1988

At regular intervals each week, continuously collected particulate samples are removed from each exhaust system and radiometrically analyzed for long-lived alpha radiation emitters Beginning in September 1988, the collection schedule for these samples was changed from three times a week to twice a week The concentration of long-lived alpha emitters is indicative of the effluent quality and the overall performance of the HEPA filtration systems If the total long-lived alpha concentration for an effluent sample exceeds the plant action guide value of $0\,020 \times 10^{-12}$ µCi/ml ($7\,4 \times 10^{4}$ Bq/m^3), a follow-up investigation is conducted to determine the cause and to evaluate the need for corrective action The action guide is equal to the offsite Derived Concentration Guide (DCG) for plutonium activity in air No exceedances of the alpha activity action guide occurred during 1988

At the end of each month, samples for each exhaust system are composited into individual samples which

5. Monitoring Data

undergo specific chemical analysis An aliquot of each of the dissolved composite-samples is analyzed for beryllium particulates using a flameless atomic absorption spectrometry technique (BO68) The remainder of the dissolved sample is subjected to chemical separation and alpha spectral analysis that quantifies specific alpha-emitting radionuclides Analyses for uranium isotopes are conducted for each composite sample In 1988, forty-two of the ventilation exhaust systems were located in buildings containing plutonium Particulate samples from these exhaust systems also were analyzed for specific isotopes of plutonium and americium Typically americium contributes only a small fraction of the total alpha activity airborne release for the Plant, and americium-specific airborne effluent data have not been reported in previous annual site reports Beginning with this report for CY1988, americium-specific airborne effluent measurements are included in the reported data

Several exhaust systems service processes having a potential for trace quantities of tritium contamination From January through August, 1988, continuous sampling for tritium was conducted in 23 ventilation exhaust systems In September, 1988, the tritium airborne effluent monitoring program was modified to delete those monitoring locations which were identified as no longer having a potential to contribute to the total tritium release Bubbler-type samplers are used to continuously collect samples which are exchanged three times each week from the monitored locations Tritium concentrations in the samples are measured using a liquid scintillation photospectrometer

Tables 2 and 3 present the quantitative data for radioisotopes in airborne effluents during 1988 Tritium values include small contributions from background (i e , non-plant) sources of tritium

During 1988, the total quantity of plutonium and americium discharged to the atmosphere from the plutonium exhaust systems were 15 33 μCi (5 67 X 10^5 Bq) and 2 02 μCi (7 47 X 10^4 Bq), respectively

The maximum plutonium and americium air concentrations were measured from a waste treatment facility during June, when a concentration of 0 023 X 10^{-12} μCi/ml (8 52 X 10^{-4} Bq/m^3) was measured for plutonium and a concentration of 0 008 X 10^{-12} μCi/ml (2 96 X 10^4 Bq/m^3) was measured for americium The quantity of plutonium in this discharge was 0 318 μCi (1 18 X 10^4 Bq) and the quantity of americium was 0 105 μCi (3 89 X 10^3 Bq) Samples collected prior to and following this two-day period were within the range typically measured from this exhaust system In September 1988, operations in the plant's primary plutonium recovery processing facility were suspended in order to accomplish upgrades to safety systems and to perform a general cleanup of the facility A phased-in restart of the facility began in January, 1989 The decrease in plutonium and americium release activities reported for September through December, 1988 reflect the suspension of activities in this building

The total discharge of uranium from all the exhaust systems was 11 93 μCi (4 41 X 10^5 Bq) The maximum uranium concentration of 0 009 X 10^{-12} μCi/ml (3 33 X

TABLE 2 Plutonium and Americium in Airborne Effluents

	Plutonium[a]			Americium[b]		
Month	Number of Analyses	Total Discharge (μCi)	C_{max}[c] ($X 10^{-12}$ μCi/ml)	Number of Analyses	Total Discharge (μCi)	C_{max}[c] ($X10^{-12}$ μCi/ml)
January	45	1 10	0 004 ± 0 005[d]	45	0 17	0 001 ± 0 0001[d]
February	47	2 32	0 013 ± 0 014	47	0 24	0 005 ± 0 0006
March	47	2 73	0 010 ± 0 024	47	0 29	0 001 ± 0 0002
April	47	1 18	0 005 ± 0 007	47	0 11	0 001 ± 0 0006
May	47	1 84	0 015 ± 0 017	47	0 26	0 001 ± 0 0006
June	47	1 01	0 023 ± 0 052	47	0 24	0 008 ± 0 0011
July	47	1 79	0 012 ± 0 013	47	0 23	0 001 ± 0 0002
August	47	1 75	0 010 ± 0 010	47	0 25	0 004 ± 0 0006
September	47	0 40	0 010 ± 0 011	47	0 05	0 001 ± 0 0002
October	47	0 66	0 007 ± 0 008	47	0 09	0 001 ± 0 0002
November	47	0 25	0 003 ± 0 003	47	0 04	0 001 ± 0 0002
December	47	0 30	0 001 ± 0 001	47	0 05	0 000 ± 0 0000
Summary	562	15 33	0 023 ± 0 052	562	2 02	0 008 ± 0 0011

a Radiochemically determined as plutonium-239, -240
b Radiochemically determined as americium -241
c C_{max} is the maximum measured concentration
d Calculated as 1 96 standard deviations on an individual measurement

10^{-4}Bq/m^3) was measured from a depleted uranium production facility in February The quantity of depleted uranium from this discharge was 0 344 μCi (1 27 X 10^4 Bq)

The tritium discharged from the plant ventilation systems was 0 015 Ci (5 55 x 10^8 Bq) The maximum tritium concentration of 417 X 10^{-12} μCi/ml (1 54 X 10^1 Bq/m^3) was observed in a sample from a routine operation in a plutonium production building during February The quantity of tritium released to the atmosphere as a result of this operation was 432 μCi (1 60 X 10^7 Bq)

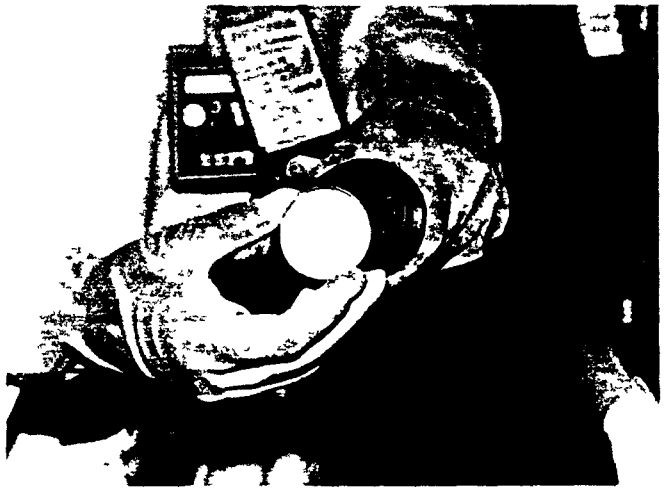
Overall, the radionuclide releases to the atmosphere during 1988 were not significantly different from those

5. Monitoring Data

TABLE 3 Uranium and Tritium in Airborne Effluents

Month	Uranium[a] Number of Analyses	Uranium[a] Total Discharge (μCi)	Uranium[a] C_{max}[c] ($\times 10^{-12}$ μCi/ml)	Tritium[b] Number of Analyses	Tritium[b] Total Discharge (Ci)	Tritium[b] C_{max}[c] ($\times 10^{-12}$ μCi/ml)
January	53	2.23	0 005 ± 0 0005[d]	261	-0 001	188 + 100[d]
February	55	2 00	0 009 ± 0 0009	260	0 006	417 + 250
March	55	1 49	0 004 ± 0 0024	275	-0 003	135 + 100
April	55	1 33	0 006 ± 0 0007	262	0 006	250 + 180
May	55	0 82	0 004 ± 0 0004	278	-0 002	243 + 150
June	55	0 87	0 004 ± 0 0004	275	0 002	194 + 120
July	55	0.59	0 004 ± 0 0004	240	0 004	100 + 120
August	55	0 72	0 004 ± 0 0004	211	0 001	194 + 100
September	55	0 26	0 002 ± 0 0003	41	0 000	139 + 120
October	55	0.58	0 003 ± 0 0004	65	0 000	97 + 155
November	55	0 39	0 001 ± 0 0001	65	0 001	83 + 165
December	55	0 65	0 001 ± 0 0002	70	0 001	104 + 120
Summary	658	11 93	0 009 ± 0 0009	2303	0 015	417 + 250

a Radiochemically determined as uranium -233, -234, and -238
b Tritium is hydrogen-3
c C_{max} is the maximum measured concentration
d Calculated as 1 96 standard deviations on an individual measurement



Collecting Effluent Air Particulate Samples

Direct Alpha Activity Check Prior to Effluent Air Sample Collection

TABLE 4 Beryllium in Airborne Effluents

	Beryllium		
Month	Number of Analyses	Total Discharge[a] (g)	C_{max}[b] ($\mu g/m^3$)
January	53	0 0395	0 00031
February	55	0 0018	0 00003
March	55	0 0129	0 00041
April	55	0 0131	0 00031
May	55	0 0200	0 00033
June	55	0 0159	0 00025
July	55	0 0067	0 00016
August	55	0 0101	0 00021
September	55	0038	0 00012
October	55	0 0058	0 00005
November	55	0 0102	0 00010
December	55	0 0061	0 00007
Summary	658	0 1383[c]	0 00041

a The beryllium stationary-source emission-standard is no more than 10 grams of beryllium over a 24-hour period under the provisions of subpart C of 40 CFR 61 2 (a) (US78)

b C_{max} is the maximum measured concentration

c This value is not significantly different from the background associated with the analyses

in 1987 The atmospheric releases are within the normal ranges projected in the Plant Environmental Impact Statement, and represent no adverse environmental impact

Table 4 presents the beryllium airborne effluent data for 1988 The total quantity of beryllium discharged from the ventilation exhaust systems was not significantly above the background levels associated with the analyses and was well within the CDH and EPA standards for beryllium under the Clean Air Act

B. Radioactive Ambient Air Monitoring

Ambient air samplers are located in the Rocky Flats plantsite operations area, at the plant perimeter [at distances of approximately 3 to 6 kilometers (2 to 4 miles) from the plant's center], and in surrounding communities These Rocky Flats-designed air samplers operate continuously at a volumetric flow rate of approximately 12 l/s (25 ft^3/min), collecting air particulates on 20- X 25-cm (8- X 10-in) fiberglass media Manufacturer's test specifications rate this filter media to be 99 97% efficient for the relevant particle sizes under conditions typically encountered in routine ambient air sampling (SC82)

Airborne particulates in ambient air are sampled continuously at 23 locations within and adjacent to the Rocky Flats Plant operations area (Figure 7) The sample filters are collected biweekly and analyzed for total long-lived alpha (TLLα) radiation If the TLLα activity for an ambient air sample exceeds the plant guide value [10 X 10^{-15} μCi/ml (3 7 X 10^{-4} Bq/m^3)], a

5. Monitoring Data

specific plutonium analysis is performed During 1988, four samples exceeded the TLLα screening level and were analyzed for plutonium The results of these analyses have been included in Table 5

Filters from 5 of the 23 onsite samplers are routinely analyzed biweekly for plutonium These five onsite samplers have historically shown the highest TLLα activities for the sampling network Table 5 contains the mean concentrations of plutonium in ambient air at these stations during 1988, as well as the minimum and maximum concentrations measured throughout the year

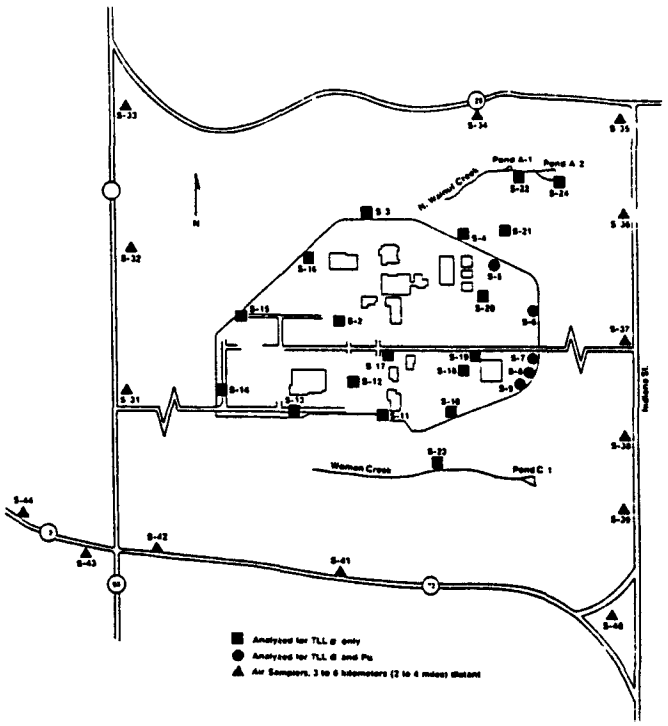


FIGURE 7 Location of Onsite and Plant Perimeter Ambient Air Samplers

The mean concentrations of plutonium in ambient air at the five onsite stations during 1988 ranged from 0.149×10^{-15} to 0.710×10^{-15} µCi/ml (5.51×10^{-6} to 2.63×10^{-5} Bq/m^3) These concentrations are less than four percent of the offsite Derived Concentration Guide (DCG) for plutonium in air

Monitoring for tritium in ambient air was conducted from January 6 to July 26, 1988, at onsite locations S-4, S-5, and S-16 (Figure 7) Samples were collected and analyzed weekly The tritium samplers operated continuously at a sampling rate of one-to-two liters of air per minute Water vapor in the sampled air was collected in a Pyrex tube filled with silica gel Table 6 presents the mean concentrations of tritium measured in ambient air at these three onsite stations during the January through July monitoring period Annual mean concentration of tritium in ambient air at the three onsite stations ranged from -0.07×10^{-12} to -0.06×10^{-12} µCi/ml air (-2.6×10^{-3} to -2.2×10^{-3} Bq/m^3) The ambient tritium in air monitoring program was discontinued in July, 1988 with the decommissioning of the Solar Evaporation Ponds. The Solar Evaporation Ponds were replaced by two tanks (950,000 and 250,000 gallons) constructed to Colorado Department of Health regulations for storage of hazardous waste solutions

Samples of airborne particulates are collected on filters by ambient air samplers at 14 locations along or near the plant perimeter These perimeter samplers are located between 3 and 6 kilometers (2 and 4 miles)

TABLE 5 Plutonium-239 and -240 Activity Concentrations in Onsite Ambient Air at Selected Locations[a]

Station	Number of Analyses	Volume (X 1000 m^3)[d]	Concentration[b] (x 10^{-15} µCi/ml)[c]			Standard Deviation	Percent of DCG[e]
			C_{min}	C_{max}	C_{mean}	(C_{mean})	(C_{mean})
S-5	25	331	0 054	1 389	0 389	0 357	1 95
S-6	26	344	0 027	0 460	0 149	0 111	0 75
S-7	26	328	0 045	1 171	0 515	0 369	2 58
S-8	26	418	0 114	1 246	0 710	0 366	3 55
S-9	26	376	0 205	1 179	0 641	0 286	3 21
S-6[f]	1	11	NA[g]	NA	0 059	NA	0 30
S-7	1	12	NA	NA	0 664	NA	3 32
S-8	1	17	NA	NA	2 129	NA	10 65
S-9	1	12	NA	NA	1 281	NA	6 41

a Air-sampling stations S-5, S-6, S-7, S-8, and S-9 are located in areas where the potential for elevated airborne radioactivity is greatest (see Figure 7)

b Concentrations reflect monthly composites of biweekly station concentrations C_{min} = minimum composited concentration, C_{max} = maximum composited concentration, C_{mean} = mean composited concentration

c To obtain the proper concentration, multiply the numbers listed in the table by 1 X 10^{15} µCi/ml For example, the mean concentration at S-5 was 0 389 X 10^{15} µCi/ml

d To obtain the proper volume, multiply the numbers listed in the table by 1000 m^3 For example, the air volume sampled at S-5 was 331,000 m^3

e The interim standard calculated Derived Concentration Guide (DCG) for inhalation of class W plutonium by members of the public is 20 X 10^{15} µCi/ml (See Appendix A) Protection standards for members of the public are applicable for offsite locations All locations in this table are on Rocky Flats Plant property The DCGs for the public are presented here for comparison purposes only

f Samples from stations S-6 (taken 8/9/88 to 8/23/88), S-7 (taken 4/19/88 to 5/3/88), S-8 (taken 11/29/88 to 12/13/88), and S-9 (taken 8/23/88 to 9/6/88) exceeded the screening guide of 10 x 10^{15} µCi/ml total long-lived alpha activity Specific plutonium analyses were performed on these samples The results of these analyses are included for completeness

g NA=Not Applicable

5. Monitoring Data

TABLE 6 Tritium Activity Concentrations in Onsite Ambient Air
(01/06/88-07/26/88)

Station	Number of Analyses	Air Volume (m^3)	Condensed Water Vapor (mls)	Concentration[a] (x 10^{-12} µCi/ml air)[b] C_{min}	C_{max}	C_{mean}	Standard Deviation (C_{mean})	Percent of DCG[c] (C_{mean})
S-4	27	1695	805	-0 99 ± 1 24	0 28 ± 0 71	-0 06	0 43	0
S-5	25	203	452	-0 60 ± 1 74	0 14 ± 1 27	-0 06	0 25	0
S-16	24	288	603	-0 92 ± 1 50	0 23 ± 0 83	-0 07	0 39	0

a Concentrations reflect monthly composites of station concentrations C_{min} = minimum composited concentration, C_{max} = maximum composited concentration, C_{mean} = mean composited concentration

b To obtain the proper concentration, multiply the number in the table by 1 X 10^{12} µCi/ml For example, the mean concentration at S-4 was -0 06X 10^{12} µCi/ml

c The interim standard calculated offsite Derived Concentration Guide (DCG) for tritium in air is 200,000 X 10^{12} µCi/ml (See Appendix A)

from the plant center (Figure 7) The samplers are numbered S-31 through S-44 Samples from each location are collected biweekly, composited by location, and analyzed monthly for plutonium. Table 7 presents the average concentrations of plutonium radioactivity in airborne particulates at Stations S-31 through S-44 during 1988 The mean concentration of plutonium in ambient air at these locations during 1988 was 0 003 X 10^{-15} µCi/ml (1 11 X 10^{-7} Bq/m^3) This concentration is 0 01 percent of the offsite DCG for plutonium in air

Samples of airborne particulates are also collected at 14

Collecting Ambient
Air Particulate Sample

TABLE 7 Plutonium-239 and -240 Activity Concentrations in Perimeter Ambient Air

Station	Number of Analyses	Volume[c] (X 1000 m^3)	Concentration[a] (x 10^{-15} µCi/ml)[b] C_{min}	C_{max}	C_{mean}	Standard Deviation (C_{mean})	Percent of DCG[d] (C_{mean})
S-31	12	268	0 000	0 014	0 003	0 004	0 02
S-32	12	296	-0 002	0 009	0 002	0 003	0 01
S-33	12	375	-0 001	0 007	0 002	0 002	0 01
S-34	12	371	-0 001	0 041	0 006	0 012	0 03
S-35	12	319	-0 001	0 002	0 001	0 001	0 00
S-36	12	327	0 000	0 011	0 004	0 004	0 02
S-37	12	410	0 001	0 027	0 010	0 008	0 05
S-38	12	324	0 000	0 019	0 006	0 006	0 03
S-39	12	384	0 000	0 008	0 002	0 002	0 01
S-40	12	396	-0 001	0 002	0 001	0 001	0 00
S-41	12	346	-0 001	0 004	0 001	0 001	0 01
S-42	12	333	0 000	0 004	0 001	0 001	0 01
S-43	12	362	-0 001	0 005	0 001	0 002	0 00
S-44	12	367	-0 001	0 008	0 001	0 002	0 00
Overall	168	4878	-0 002	0 041	0 003	0 005	0 01

a Concentrations reflect monthly composites of filters by station locations C_{min} = minimum concentration, C_{max} = maximum concentration, C_{mean} = mean concentration

b To obtain the proper concentration, multiply the numbers listed in the table by 1 X 10^{-15} µCi/ml For example, the mean concentration at S-31 was 0 003 X 10^{-15} µCi/ml

c To obtain the proper volume, multiply the number listed in the table by 1000 m^3 For example, the air volume sampled at S-31 was 268,000 m^3

d The interim standard calculated Derived Concentration Guide (DCG) for inhalation of class W plutonium by members of the public is 20 X 10^{-15} µCi/ml Differences in percent of DCG for the same reported mean concentration are the result of rounding differences utilizing raw data

locations in or near communities in the vicinity of the Rocky Flats Plant These locations, shown in Figure 8, are Boulder, Broomfield, Cotton Creek, Denver, Golden, Jeffco Airport, Lafayette, Lakeview Pointe, Leyden, Marshall, Superior, Wagner, Walnut Creek, and Westminster Sample filters are collected biweekly, composited by location, and analyzed monthly for plutonium radioactivity Table 8 presents the average concentrations of plutonium in airborne particulates at the community stations during 1988 The mean concentration of plutonium in ambient air at the community stations was 0 002 X 10^{-15} µCi/ml (7 40 X 10^{-8} Bq/m^3) This value is 0 01 percent of the offsite DCG for plutonium in air

5. Monitoring Data

TABLE 8 Plutonium-239 and -240 Concentrations in Community Ambient Air

Station	Number of Analyses	Volume (X 1000 m^3)[c]	Concentration[a] (x 10^{-15} µCi/ml)[b]			Standard Deviation	Percent of DCG[d]
			C_{min}	C_{max}	C_{mean}	(C_{mean})	(C_{mean})
S-51 Marshall	12	287	-0 003	0 002	0 000	0 001	0 00
S-52 Jeffco Airport	12	390	-0 001	0 012	0 003	0 004	0 02
S 53 Superior	12	312	-0 001	0 050	0 005	0 014	0 03
S-54 Boulder	12	361	-0 002	0 028	0 003	0 008	0 02
S-55 Lafayette	12	361	-0 001	0 035	0 004	0 010	0 02
S-56 Broomfield	12	336	-0 002	0 004	0 001	0 002	0 00
S-57 Walnut Creek	12	365	-0 001	0 004	0 001	0 002	0 01
S-58 Wagner	12	348	0 001	0 013	0 004	0 003	0 02
S-59 Leyden	12	396	-0 001	0 010	0 002	0 003	0 01
S-60 Westminster	12	255	-0 002	0 009	0 002	0 003	0 01
S-61 Denver	10	220	-0 002	0 007	0 001	0 003	0 01
S-62 Golden	11	305	-0 001	0 008	0 001	0 003	0 01
S-68 Lakeview Pointe	12	397	-0 002	0 010	0 002	0 003	0 01
S-73 Cotton Creek	12	341	-0 001	0 005	0 001	0 002	0 00
Overall	165	4674	-0 003	0 050	0 002	0 006	0 01

a Concentrations reflect monthly composites of filters by station locations C_{min} = minimum concentration, C_{max} = maximum concentration, C_{mean} = mean concentration

b To obtain the proper concentration, multiply the numbers listed in the table by 1 X10 ^{15} µCi/ml For example, the mean concentration at Marshall was 0 000 X 10 ^{15} µCi/ml

c To obtain the proper volume, multiply the numbers listed in the table by 1000 m^3 For example, the air volume sampled at Marshall was 287,000 m^3

d The interim standard calculated offsite Derived Concentration Guide (DCG) for inhalation of class W plutonium by members of the public is 20 X 10^{-15} µCi/ml Differences in percent for DCG for the same reported mean concentration are the result of rounding differences utilizing raw data

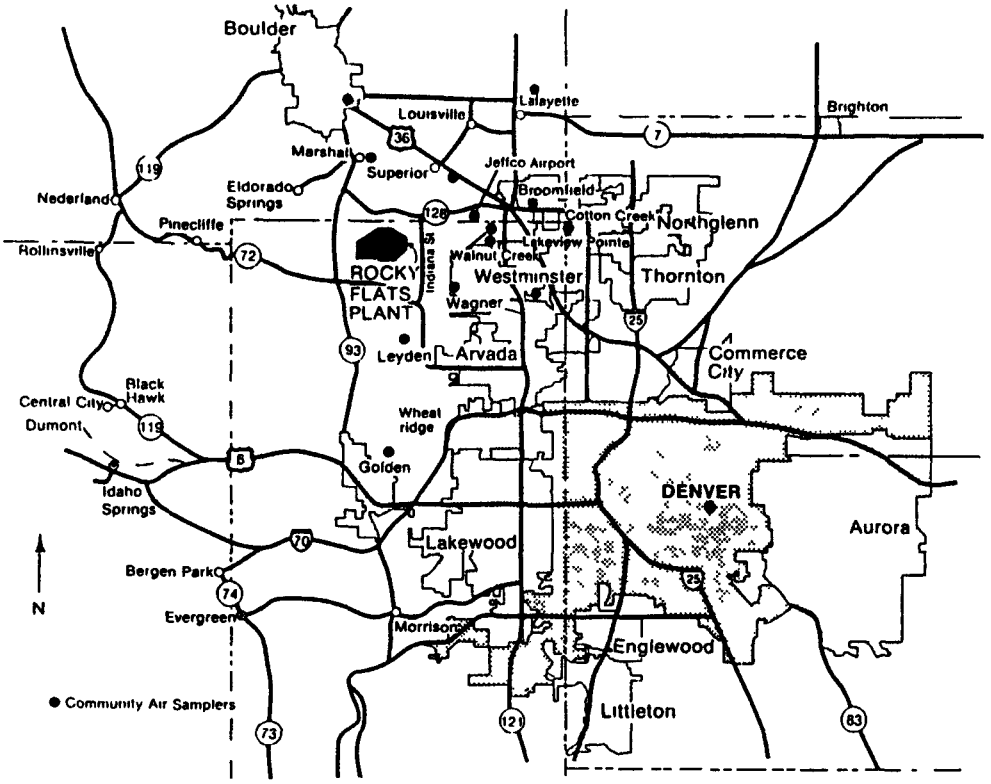


FIGURE 8 Location of Community Ambient Air Samplers

C. Nonradioactive Ambient Air Monitoring

During 1988, monitoring of ambient air included the following parameters suspended particulates, ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide, and lead This monitoring utilized instrumentation in a self-contained shelter equipped for field sampling of ambient air These six parameters are criteria pollutants regulated by the Environmental Protection Agency (EPA) and the State of Colorado through the Clean Air Act Amendments of 1970 and 1977, which include the National Ambient Air Quality Standards (NAAQS) and Colorado Air Quality Control Commission Ambient Air Standards Regulation of criteria pollutants by EPA and the State of Colorado is conducted on a regional basis, rather than for any individual facility The Rocky Flats Plant monitoring program for these pollutants has been conducted to provide baseline information on criteria pollutant air concentrations in this area

Table 9 identifies the detection methods and operating ranges of the monitoring analyzers with correspond-

TABLE 9 1988 Ambient Air Monitoring Detection Methods and National Ambient Air Quality Standards (NAAQS) for Particulates, Ozone, Sulfur Dioxide, Carbon Monoxide, Nitrogen Dioxide, and Lead

Parameter	Detection Methods and Analyzer Ranges	NAAQS Averaging Time	Concentration
Total Suspended Particulates (TSP)	Reference Method (Hi Volume) 24-Hour sampling (6th-day scheduling)	Annual Geometric Mean Primary[a]	75 µg/m^3
		Secondary[b]	60 µg/m^3
		24-Hour Primary[a,c]	260 µg/m^3
		Secondary[b c]	150 µg/m^3
PM 10 (Particulate Matter less than 10 micrometers in diameter)	Wedding PM-10 Sampler	Primary Annual Arithmetic Mean	50 µg/m^3
		24-Hour Average	150 µg/m^3
Ozone (O_3)	ThermoElectron Model 49 Ultraviolet Photometry 0-0 5 ppm	1-Hour Primary[a d]	0 12 ppm
Sulfur Dioxide (SO_2)	ThermoElectron Model 43 Pulsed Fluorescence 0-0 5 ppm	Annual Arithmetic Mean Primary[a]	0 030 ppm
		24-Hour Primary[a]	0 140 ppm
		3-Hour Secondary	0 500 ppm
Carbon Monoxide (CO)	ThermoElectron Model 48 Gas Filter Correlation (infrared) 0-50 ppm	1-Hour Primary[a c]	35 ppm
		8-Hour Primary[a c]	9 ppm
Nitrogen Dioxide (NO_2)	Monitor Labs Model 8840 Chemiluminescent 0-0 5ppm	Annual Arithmetic Mean Primary[a]	0 05 ppm
Lead	Reference Method (Hi Volume) 24-Hour Sampling (Atomic Absorption Analysis)	Calendar Quarter Primary[a]	1 5 µg/m^3

a Primary NAAQS are intended to protect public health
b Secondary NAAQS are intended to protect public welfare
c Not to be exceeded more than once per year
d Statistically estimated number of days with concentrations in excess of the standard is not to be more than 1 0 per year

ing regional compliance standards During 1988, the monitoring shelter was at a location near the east entrance (gate 10) to the plant This is an open area near a traffic zone and is generally downwind from plant buildings Ambient air data were collected over the entire year with some limited loss of data due to equipment malfunction during the fourth quarter

Final EPA respirable particulates (PM-10) standards were issued July 1, 1987 (US87a) Reference methods for this new PM-10 standard were issued by EPA on October 6, and December 1, 1987 (US87b) The PM-10 sampler that the Rocky Flats Plant has in use is one of the two accepted sampler designs specifically described in the October 6, 1988, Federal Register Two co-located PM-10 samplers began operations in the second quarter of the 1988 sampling period The reference method for ambient lead sampling is still the high-volume sampler The use of both TSP and PM-10 sampling is encouraged by CDH until specific changes are made in state regulations that reflect the PM-10 changes in the federal regulations

Measurements of TSP and lead were conducted using the EPA reference high-volume air sampling method The primary ambient air particulate sampler and a co-located duplicate sampler were operated on the EPA's sampling schedule of once every sixth day Particulate data are shown in Table 10 The highest TSP value recorded in 1988 (a 24-hour sample) was 83 $\mu g/m^3$, which is 32 percent of the former 24-hour primary standard of 260 $\mu g/m^3$ The annual geometric mean value for 1988 was 39 5 $\mu g/m^3$, which was 53 percent of the old TSP primary annual geometric mean standard of 75 $\mu g/m^3$ The annual arithmetic mean for the primary PM-10 sampler (unit "C") was 15 8 $\mu g/m^3$, which was 32 percent of the Primary Annual Arithmetic Mean of 50 $\mu g/m^3$ The observed 24-hour maximum was 39 1 $\mu g/m^3$, which was 26 percent of the Primary 24-hour Standard of 150 $\mu g/m^3$

The quarterly average lead concentrations in air (taken from high-volume samples) for 1988 were well below the primary quarterly standard of 1.5 $\mu g/m^3$ The highest quarterly value detected was 0 020 $\mu g/m^3$ collected during January, February and March, which is less than two percent of the EPA standard

Ambient ozone data were collected using an ultraviolet (U V) photometric type analyzer During 1988, a total of 6,526 one-hour ozone samples were collected The maximum one-hour value was 0 090 ppm, which is 75 percent of the primary one-hour standard of 0 120 ppm These values are consistent with levels measured in the general Denver metropolitan area during 1988 (CO88) Calibration of this analyzer was done with a primary standard U V photometer

Sulfur dioxide sampling was conducted using a continuously operating pulsed fluorescence type analyzer calibrated by use of a certified cylinder gas and a dynamic gas dilution calibration system The cylinder gases, as well as the mass flowmeters, have traceability to primary standards set by the National Bureau of Standards The maximum one-hour SO_2 value recorded at the plant was 0 021 ppm and the maximum

5. Monitoring Data

TABLE 10 Onsite Ambient Air Quality Data (Nonradioactive Parameters)-1988

Total Suspended Particulates ($\mu g/m^3$)	
Total Number of Samples, "A"[a]	61
Total Number of Samples, "B"[b]	61
Annual Geometric Mean, Sampler "A"	39 5
Annual Geometric Mean, Sampler "B"	37 1
Standard Deviation, Sampler "A"	20 1
Standard Deviation, Sampler "B"	19 2
Observed 24-Hour Maximum, "A"	83 3
Observed 24-Hour Maximum, "B"	80 6
Second Highest Maximum, "A"	80 5
Second Highest Maximum, "B"	75 2
Lowest Observed Value, "A"	7 0
Lowest Observed Value, "B'	7 5
Respirable Particulates (PM-10) ($\mu g/m^3$)	
Total Number of Samples, "C"	38
Total Number of Samples, "D"	40
Annual Arithmetic Mean, "C"	15 8
Annual Arithmetic Mean, "D"	14 3
Observed 24-Hour Maximum, "C"	39 1
Observed 24-Hour Maximum, "D"	36 8
Second Highest Maximum, "C"	35 9
Second Highest Maximum, "D"	33 7
Ozone (ppm)	
Number of Observations, Hourly[c]	6,526
Arithmetic Mean, Annual	0 032
Maximum 1-Hour Concentration	0 090
Second Highest 1-Hour Concentration	0 090
Minimum Observation, Hourly	0 003

a Primary ambient air particulate sampler
b Co-located duplicate sampler
c Continuous millivolt analyzer output is composited and converted to engineering units for comparison to NAAQS (see Table 9)

observed three-hour average value was 0 019 ppm, which is four percent of the EPA three-hour standard of 0 500 ppm The calculated annual arithmetic mean value of 0 003 ppm is ten percent of the NAAQS annual arithmetic mean standard of 0 030 ppm The maximum observed 24-hour average for SO_2 was 0 009 ppm, which is six percent of the NAAQS 24-hour standard of 0 140 ppm

The 6,500 hourly averages of carbon monoxide (CO) data collected during 1988, using a gas filter correlation infrared type analyzer, yielded an annual arithmetic mean of 0 50 ppm, including a maximum one-hour average value of 5 00 ppm, which is 14 percent of the primary one-hour standard of 35 ppm A maximum eight-hour average concentration value of 2 00 ppm was recorded, which is 22 percent of the eight-hour primary standard of 9 ppm

The nitrogen dioxide (NO_2) data contain 5,636 hourly averages of continuous sampling and gave an annual arithmetic mean of 0 005 ppm, which is ten percent of the NAAQS primary annual arithmetic mean standard value of 0 05 ppm The maximum one-hour value noted during this time period was 0 050 ppm

All continuous analyzers were routinely checked using established precision and operational span checks multipoint dynamic calibrations, and established standard operating procedures

As part of an ongoing quality assurance program, all of the analyzers were subjected to an independent an-

TABLE 10 Onsite Ambient Air Quality Data (continued)
(Nonradioactive Parameters)-1988

Carbon Monoxide (ppm)	
Number of Observations, Hourly[c]	6,500
Arithmetic Mean, Annual	0 50
Maximum 1-Hour Concentration	5 00
Second Highest 1-Hour Concentration	4 90
Maximum 8-Hour Concentration	2 00
Minimum Hourly Observation	0 05
Nitrogen Dioxide (ppm)	
Number of Observations, Hourly[c]	5,636
Annual Arithmetic Mean	0 005
Maximum 1-Hour Concentration	0 050
Minimum Hourly Observation	0 001
Sulfur Dioxide (ppm)	
Number of Observations, Hourly[c]	6,640
Arithmetic Mean, Annual	0 003
3-Hour Average, Highest	0 019
24-Hour Average, Highest	0 009
Maximum 1-Hour Concentration	0 021

Airborne Lead ($\mu g/m^3$)

	Jan-Mar	Apr-June	Jul-Sep	Oct-Dec
Total Number of Samples	6	8	6	6
Quarterly Avg	0 020	0 008	0 019	0 016

a Primary ambient air particulate sampler
b Co-located duplicate sampler
c Continuous millivolt analyzer output is composited and converted to engineering units for comparison to NAAQS (see Table 9)

nual audit during 1988 Responses of all but the NO_2 analyzer were within the established EPA guidelines for ambient air monitoring networks (± 15 percent) The oxides of nitrogen analyzer indicated a converter efficiency of less than 90 percent Maintenance procedures were conducted based on this operational indicator

Review of the NAAQS data for EPA Criteria Pollutants over the past several years has provided a baseline database for plant site needs Cost benefit analysis and the absence of site-specific regulations mandating this monitoring have resulted in a rescoping of this program All parameters except for the sampling of particulates will be discontinued concurrent with publication of this report The sampling of total suspended and respirable (PM-10) particulates will continue to provide a database for comparative trend analysis

D. Waterborne Effluent Monitoring

North Walnut Creek receives surface water runoff from the north side of the plantsite (See Figure 4) Holding Pond A-3 on North Walnut Creek is used to impound this surface runoff for analysis prior to discharge A second control point, flood control Pond A-4 is located further downstream

Ponds A-1 and A-2 are isolated by valves from North Walnut Creek In the past, these ponds have been used for storage and evaporation of laundry water This practice was discontinued in 1980 These ponds currently are maintained in a state of readiness for control of possible chemical spills into the North Walnut Creek drainage basin Disposition of Pond A-1 and A-2 runoff water is through natural evaporation and is enhanced by spraying water through fog nozzles over the surface of the ponds Excess water that does not evaporate is then recollected by the ponds

South Walnut Creek receives surface water runoff from the central portion of the plant This water is diverted through a culvert system to Pond B-4 and then to flood control Pond B-5 where the water is impounded for analysis prior to controlled offsite discharge

In the past, treated sanitary wastewater also was routinely discharged to South Walnut Creek This practice was discontinued in 1979 Currently, discharges to South Walnut Creek following impoundment in Pond B-5 occur only when weather conditions do not permit onsite spray irrigation During 1988 treated sanitary wastewater was discharged directly to Pond B-3 to be used for spray irrigation onto Rocky Flats Plant buffer zone areas or for discharge to Pond B-5 during inclement weather conditions Pond B-5 is discharged under controlled conditions when Pond B-3 discharges, precipitation runoff, or a combination of the two sources require it Ponds B-1 and B-2, also located in the central drainage, are reserved as backup control ponds These ponds can be used to retain chemical spills, surface water runoff, or treated sanitary wastewater within the limits of their combined capacities

46

5. Monitoring Data

Surface runoff water from the south side of the plant is collected in an interceptor ditch and flows to surface water control Pond C-2, where the water is impounded and analyzed before discharge Woman Creek, also in the south drainage, is isolated from this diversion system Pond C-1 is used as the monitoring point for Woman Creek

Discharges from the Rocky Flats Plant are monitored for compliance with appropriate Colorado Department of Health Standards and EPA National Pollutant Discharge Elimination System (NPDES) permit limitations (US84a) Annual average concentrations of chemical and biological constituents of liquid effluent samples collected from Ponds A-3, A-4, B-3, B-5, and C-2 during 1988 are presented in Table 11. The data are indicative of overall water quality for these ponds

During 1984, the plant NPDES permit expired and was replaced by a renewed NPDES permit with the same seven discharge locations 001, 002, 003, 004, 005, 006 and 007 The discharge locations are identified in Table 11 The NPDES permit places monitoring and reporting requirements and limitations on daily concentrations and monthly average concentrations for specific parameters There were violations of the NPDES permit during some months of 1988 The violations consisted of exceedance of the allowable Biochemical Oxygen Demand (BOD_5) limits during the months of February, March, April, and May and of the allowable fecal coliform limit for April, 1988 Table 12 summarizes the 1988 NPDES Permit exceedances

The probable cause of the violations to BOD_5 permit limits has been attributed to inability to remove sludge from the Sewage Treatment Plant (STP) during cold and wet weather and to sludge drying and disposal limitations These conditions diminish the efficiency of the treatment system because the aging sludge which results becomes less biologically active for treating the waste Lower efficiency in the treatment process results in higher levels of BOD_5 in the waters being discharged from the facility This problem is common to similar treatment systems throughout the State and country Rocky Flats Plant has commissioned studies by independent consultants of both the STP and holding ponds to be performed during the winter and spring seasons The STP studies are designed to characterize and optimize processes in that facility

One of the corrective actions initiated to provide relief from the STP sludge removal problem includes installation of an experimental polyurethane tile drying bed The completion date of this drying bed is projected for spring 1989

Another corrective action initiated to correct the fecal coliform violation was increase of the chlorine feed rate into the disinfectant contact basin and installation of a chlorine dispersion system A dechlorination facility is scheduled for installation in the spring of 1989 to prevent chlorine violations during discharge

Studies of the holding ponds were initiated to characterize algal contributions to BOD_5 levels These stud-

5. Monitoring Data

TABLE 11 Annual Average Concentrations of Chemical and Biological Constituents in Liquid Effluents[a]

Parameters	Number of Analyses	[c] minimum[b]	[c] maximum[b]	[c] mean[b]
Discharge 001[c]				
pH,SU	43	6 8	8 1	-
Nitrate as N, mg/l	43	1 17	4 7	1 6
Total Suspended Solids, mg/l	43	0	14	3 9
Total Residual Chlorine, mg/l	43	0 09	0 2	0 1
Total Chromium, mg/l	10	<0 05	<0 05	<0 05
Total Phosphorus, mg/l	16	0 5	1 0	0 6
Fecal Coliform, #/100 ml	43	3	312	71
Biochemical Oxygen Demand (BOD_5), mg/l	15	3	>40	>15 5
Discharge 002[c]				
pH, SU	14	6 9	8 1	-
Nitrate as N, mg/l	14	0 8	4 8	2 3
Discharge 003[c]				
During 1988 there were no discharges to offsite waters from the Reverse Osmosis Pilot Plant				
Discharge 004[c]				
During 1988, there were no discharges to offsite waters from the Reverse Osmosis Pilot Plant				
Discharge 005[c]				
pH, SU	20	5 2	8 0	-
Nitrate as N, mg/l	20	0 04	3 01	1 81
Nonvolatile Suspended Solids, mg/l	20	0 0	5	1 05
Discharge 006[c]				
pH, SU	38	6 8	8 3	-
Nitrate as N, mg/l	38	0 05	2 67	1 25
Nonvolatile Suspended Solids, mg/l	36	0 0	7 0	1 2
Discharge 007[c]				
pH, SU	4	7 2	8 3	-
Nitrate as N, mg/l	4	<0 02	0 56	0 19
Nonvolatile Suspended Solids, mg/l	4	0 0	2 0	1 0

a Examples of NPDES Permit limitations are presented in Table A 2

b [c] minimum = minimum measured concentration, [c] maximum = maximum measured concentration [c] mean = mean measured concentration

c The Environmental Protection Agency NPDES discharge permit defines the discharge locations as follows
001 - Pond B-3
002 - Pond A 3
003 Reverse Osmosis Pilot Plant
004 - Reverse Osmosis Plant
005 - Pond A-4
006 - Pond B-5
007 - Pond C-2

Table 12 Summary of Rocky Flats Plant 1988 NPDES Permit Exceedances

Parameter	Reporting Period	Permit Limits		Reported Results	
		30-day Avg.	Daily Max.	30-day Avg.	Daily Max.
BOD_5 - mg/l		10[a]	25[b]		
	Feb 1988			11	—
	Mar 1988			21 3	28 5
	Apr 1988			>27	>40
	May 1988			11	—
		30-day Avg.	7-day Avg.	30-day Avg.	7-day Avg.
Fecal Coliform No /100 ml		200[c]	400[c]		
	Apr 1988			312	—

a This limitation shall be determined by the arithmetic mean of a minimum of three (3) consecutive samples taken on separate weeks in a 30 day period

b Any single analysis and/or measurement beyond this limitation shall be considered a violation of the conditions of this permit

c Averages for Fecal Coliform shall be determined by the geometric mean of a minimum of three (3) consecutive grab samples taken during separate weeks in a 30-day period for the 30-day average, and during separate days in a 7-day period for the 7-day average (minimum total of three (3) samples)

ics, which are still in process, are indicating that significant contributors to the elevated BOD_5 values from the Pond B-3 discharge site are high algal populations and other factors unrelated to the STP operations

No violations to the Rocky Flats Plant NPDES permit have occurred since May, 1988

Prior to discharge from Ponds A-4, B-5, and C-2, water is sampled and analyzed for gross alpha, gross beta, tritium, gamma activity, pH, nitrate as nitrogen (N), and nonvolatile suspended solids Water is not released if the plant action level for any parameter is exceeded In general, these action levels are based on EPA and CDH drinking water standards

5. Monitoring Data

Collection of Grab Water Sample

During releases from Ponds A-4, B-5, and C-2 in 1988, water was sampled continuously The samples were analyzed later for plutonium, uranium, americium, tritium, pH, nitrate as N, and non-volatile suspended solids Water was also sampled continuously and collected daily from the outfall of Pond C-1 and collected from the Walnut Creek at Indiana Street sampling station when there was flow Daily samples were taken and analyzed for tritium The daily samples were composited into weekly samples for plutonium, uranium, and americium analyses Concentrations of plutonium, uranium, americium, and tritium in water samples from the outfalls of Ponds A-4, B-5, C-1, C-2 and from Walnut Creek at Indiana Street are presented in Tables 13 and 14 All plutonium, uranium, americium, and tritium concentrations at these locations were 1 3 percent or less of the applicable DOE Derived Concentration Guides (DCGs)

As previously mentioned, surface runoff water from the Rocky Flats Plant passes through Ponds A-4, B-5, and C-2 where the water is sampled and analyzed for radionuclides during the discharge process During 1988, the cumulative amounts of plutonium from Ponds A-4, B-5, and C-2 were $2\,9 \times 10^{-5}$ Ci ($1\,1 \times 10^{6}$ Bq), $8\,0 \times 10^{-5}$ Ci ($3\,0 \times 10^{6}$ Bq), and $8\,8 \times 10^{-6}$ Ci ($3\,3 \times 10^{5}$ Bq), respectively The yearly cumulative totals for uranium, were $8\,37 \times 10^{-3}$ Ci ($3\,1 \times 10^{8}$ Bq), $1\,56 \times 10^{-2}$ Ci ($5\,8 \times 10^{8}$ Bq), and $3\,66 \times 10^{-4}$ Ci ($1\,4 \times 10^{7}$ Bq), respectively The totals for americium were $2\,7 \times 10^{-5}$ Ci ($1\,0 \times 10^{6}$ Bq), $8\,4 \times 10^{-5}$ Ci ($3\,1 \times 10^{6}$ Bq), and $4\,1 \times 10^{-6}$ Ci ($1\,5 \times 10^{5}$ Bq), respectively

During 1988, Rocky Flats Plant raw water supply was obtained from Ralston Reservoir and from the South Boulder Diversion Canal Ralston Reservoir water usually contains more natural uranium radioactivity than the water flowing from the South Boulder Diversion Canal During the year, uranium analyses were performed monthly on samples of Rocky Flats Plant raw water The uranium concentrations measured during 1988 are presented in Table 15 Uranium concentrations measured during 1988 in raw water averaged $1\,6 \times 10^{-9}$ µCi/ml (0 06 Bq/l) or 0 002 µg/ml

Approximately 1226 gallons (4,640 l) of waste contaminated with polychlorinated biphenyls (PCBs) and low-level radioactivity are stored in approved holding facilities at the Rocky Flats Plant Some operating

TABLE 13 Plutonium, Uranium, and Americium Concentrations in Water at the Rocky Flats Plant

Location	Number of Analyses	^{c} minimum[a]	^{c} maximum[a]	^{c} mean[a]	Percent of DCG
		Plutonium Concentration (X 10^{-9} µCi/ml)[b]			
Pond A-4	5	-0 003 ± 0 030[c]	0 091 ± 0 035[c]	0 02 ± 0 03[d]	0 08
Pond B-5	15	-0 017 ± 0 054	0 08 ± 0 04	0 02 ± 0 04	0 07
Pond C-1	32	-0 03 ± 0 02	0 06 ± 0 03	0 01 ± 0 02	0 03
Pond C-2	2	0 09 ± 0 03	0 103 ± 0 038	0 10 ± 0 03	0 33
Walnut Creek at Indiana Street	26	-0 016 ± 0 025	0 034 ± 0 014	0 01 ± 0 02	0 03
		Uranium Concentration (X 10^{-9} µCi/ml)[e]			
Pond A-4	5	2 5 ± 0 2[c]	11 2 ± 1 2[c]	6 5 ± 0 7[d]	1 3
Pond B 5	15	2 1 ± 0 2	8 0 ± 0 8	3 8 ± 0 4	0 8
Pond C-1	32	-0 008 ± 0 2	3 2 ± 0 3	0 9 ± 0 2	0 2
Pond C-2	2	3 5 ± 0 3	4 5 ± 0 3	4 0 ± 0 3	0 8
Walnut Creek at Indiana Street	26	0 8 ± 0 1	12 1 ± 1 0	4 8 ± 0 5	1 0
		Americium Concentration (X 10^{-9} µCi/ml)[f]			
Pond A-4	5	0 013 ± 0 027[c]	0 03 ± 0 02[c]	0 02 ± 0 02[d]	0 07
Pond B-5	15	-0 004 ± 0 02	0 04 ± 0 05	0 02 ± 0 03	0 07
Pond C-1	32	-0 005 ± 0 023	0 060 ± 0 013	0 01 ± 0 03	0 02
Pond C-2	2	0 02 ± 0 02	0 07 ± 0 03	0 05 ± 0 03	0 17
Walnut Creek at Indiana Street	26	-0 01 ± 0 02	0 067 ± 0 032	0 01 ± 0 02	0 03

a ^{c} minimum = minimum measured concentration, ^{c} maximum = maximum measured concentration, ^{c} mean = mean measured concentration

b Radiochemically determined as plutonium -239 and -240 The interim standard calculated Derived Concentration Guide (DCG) for plutonium in water available to members of the public is 30 X 10^{-9} µCi/ml (See Appendix A)

c Calculated as 1 96 standard deviations of the individual measurement

d Calculated as 1 96 standard deviations of the mean

e Radiochemically determined as uranium -233, -234, and -238 The interim standard calculated Derived Concentration Guide (DCG) for uranium in water available to members of the public is 500 X 10^{-9} µCi/ml (See Appendix A)

f Radiochemically determined as americium -241 The interim standard calculated Derived Concentration Guide (DCG) for americium in water available to members of the public is 30 X 10^{-9} µCi/ml (See Appendix A)

5. Monitoring Data

TABLE 14 Tritium Concentrations in Water at the Rocky Flats Plant

Location	Number of Analyses	Tritium Concentration (X 10^{-9} µCi/ml) ^{c} minimum[a]	^{c} maximum[a]	^{c} mean[a]	Percent of DCG[b]
Pond A-4	5	-270 ± 290[c]	310 ± 320[c]	-60 ± 170[d]	0
Pond B-5	24	-680 ± 290	320 ± 520	-10 ± 190	0
Pond C-1	32	-600 ± 500	500 ± 360	-20 ± 130	0
Pond C-2	3	-300 ± 300	20 ± 290	-130 ± 220	0
Walnut Creek at Indiana Street	98	-570 ± 420	900 ± 380	-60 ± 140	0

a ^{c} minimum = minimum measured concentration, ^{c} maximum = maximum measured concentration, ^{c} mean = mean measured concentration

b The interim standard calculated Derived Concentration Guide (DCG) for tritium in water available to the members of the public is 2,000,000 X 10^{9} µCi/ml (See Appendix A)

c Calculated as 1 96 standard deviations of the individual measurement

d Calculated as 1 96 standard deviations of the mean

transformers contain PCBs, and each is identified, properly labeled, and protected according to EPA regulations A program is in place to replace all PCB containing transformers Analytical results from downstream waters during 1988 showed no concentrations of PCBs in excess of the analytical detection limit of approximately one part per billion

A vegetation control program using chemical herbicides was conducted at the Rocky Flats Plant during 1988 The application was completed by licensed independent contractors using EPA approved chemicals applied strictly according to the manufacturer's label Pesticides used in or near surface waters are approved by the EPA for such use Rockwell personnel conducted inspections to ensure compliance with the appropriate regulations governing application of herbicides

TABLE 15 Uranium Concentrations in the Rocky Flats Plant Raw Water Supply

Location	Number of Analyses	Uranium Concentration (X 10^{-9} µCi/ml)[a] ^{c} minimum[b]	^{c} maximum[b]	^{c} mean[b]	Percent of DCG
Rocky Flats Raw Water[c]	12	0 3 ± 0 1[d]	4 4 ± 0 3[d]	1 6 ± 0 3[e]	0 3

a Radiochemically determined as uranium-233, -234, and -238 The interim standard calculated Derived Concentration Guide (DCG) for uranium in water available to members of the public is 500 X 10^{9} µCi/ml (See Appendix A)

b ^{c} minimum = minimum measured concentration, ^{c} maximum = maximum measured concentration, ^{c} mean = mean measured concentration

c Source of raw water - Ralston Reservoir and South Boulder Diversion Canal

d Calculated as 1 96 standard deviations of the individual measurement

e Calculated as 1 96 standard deviations of the mean

E. Ground Water Monitoring

History - Ground water monitoring for radionuclides and other parameters has been conducted at the Rocky Flats Plant since the first monitoring wells were installed in 1960 Ground water monitoring wells have been periodically added to this network as appropriate By 1985, a total of 56 ground water monitoring wells had been installed at the Rocky Flats Plant A major upgrade in the monitoring program occurred in 1985 when installation of new stainless steel monitoring wells was begun to monitor for the United States Environmental Protection Agency's Resource Conservation and Recovery Act (RCRA) chemical parameters The chemicals monitored are typical of those which might be generated at hazardous waste management facilities

Environmental characterizations at Rocky Flats Plant currently are required by the U S Environmental Protection Agency (EPA), the Colorado Department of Health (CDH), and the Department of Energy (DOE) As part of a plant-wide geologic and hydrogeologic characterization in 1986 , monitoring wells were installed in the RCRA regulated units (West Spray Field, Solar Evaporation Ponds, and Present Landfill) These units received various types of regulated wastes after

5. Monitoring Data

1982 Additional RCRA-quality wells were installed at waste management sites that received various wastes prior to 1982 These sites, regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), include the High Priority Site (the 881 Hillside Area) and the Medium Priority Sites (the 903 Pad, Mound and East Trenches Areas) A total of 69 RCRA-quality wells were installed in 1986

A hydrogeologic characterization report and plans for ground water monitoring were included in the RCRA Part B permit application submitted to CDH and EPA in November, 1986 An annual report discussing the RCRA regulated units is submitted to CDH and EPA Region VIII by March 1, of every year This report addresses the current status of each RCRA regulated unit's monitoring network, contaminant concentration, location, and rate of movement

Hydrogeologic investigations continued in 1987 and consisted of the installation of 67 ground water monitoring wells Results of the investigations can be found in the Remedial Investigation Report for the 881 Hillside Area, (RI88) and the Remedial Investigation Report for the 903 Pad, Mound and East Trenches Areas, (RI87) Both of these reports can be found at the Colorado Department of Health, the Environmental Protection Agency Region VIII, and other Federal document repositories in the area

Work Plan for 1989

Ground water monitoring will be coordinated by the Plant's RCRA/CERCLA Programs with sampling and analysis on a quarterly basis for 1989 Analytical parameters are listed in Table 16

Table 16 Ground Water Monitoring Parameters

Indicators
Temperature
pH
Specific Conductance

Metals
EPA Target Analyte List Metals
(including 24 different metals)
Lithium
Cesium
Molybdenum
Strontium

Anions
Bicarbonate
Carbonate
Chloride
Nitrate
Sulfate

Organics
EPA Target Compound List VOCs
(including 34 different Volatile
Organic Compounds)

Radionuclides
Gross Alpha
Gross Beta
Uranium-233, -234, -235, -238
Americium-241
Plutonium-239, -240
Tritium

Natural variability of background concentrations for the analytes of interest in all ground water investigations at the plant must be determined in order to obtain a meaningful comparison and resolution of any

contaminant problem Therefore, a comprehensive background characterization for ground water quality has been initiated

Draft plans for additional investigation of the Medium Priority Sites - 903 Pad, Mound and East Trenches Areas - were completed in 1988 and submitted to EPA and CDH for review and comments The stratigraphic complexity of the Arapahoe Formation will be investigated using high resolution seismic reflection This program will optimize the ground water monitoring network Draft plans for the remedial investigations of the Low Priority Sites also were completed in 1988 and submitted to EPA and CDH for review and comment

Further characterization of RCRA regulated units will consist of the installation of an additional 55 ground water monitoring wells A network of approximately 126 piezometers also will be installed within the plant buildings area in order to characterize ground water flow dynamics

Geology—Surficial materials consist of the Rocky Flats Alluvium, alluvial deposits in the valleys, and colluvium (slope wash) The Rocky Flats Alluvium is topographically the highest and is the oldest of the alluvial deposits in the vicinity of the plant (See Figure 9) The Verdos Alluvium, Slocum Alluvium, Terrace Alluvium, and Recent Alluvium (lowest channel

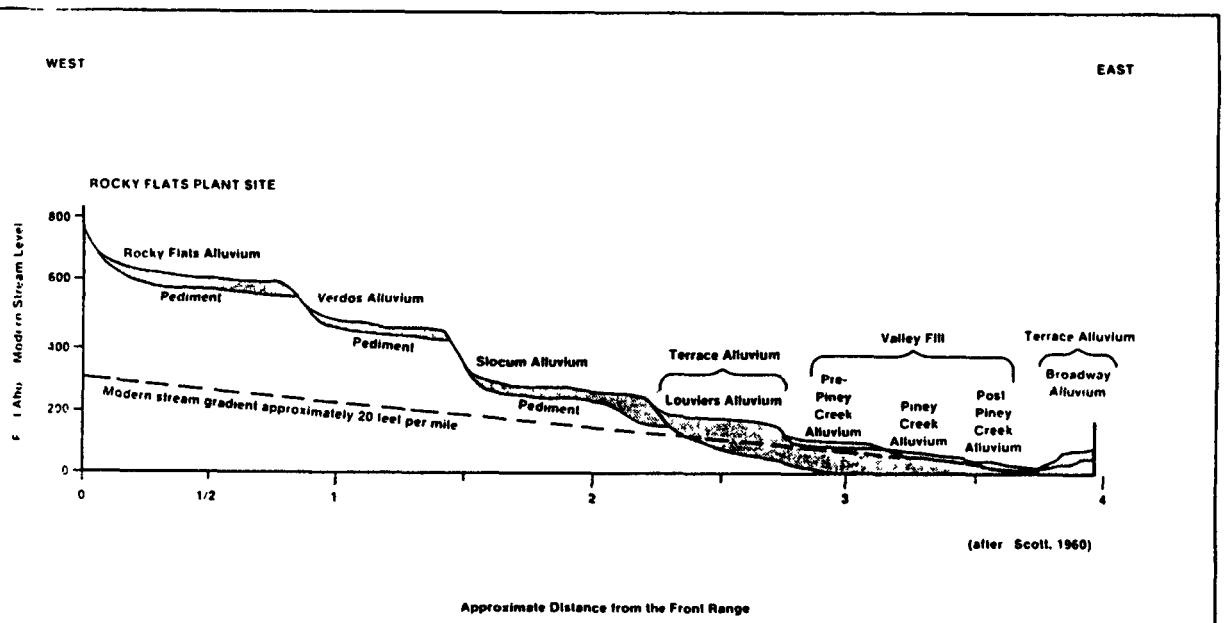


FIGURE 9 Surface Stratigraphy

55

5. Monitoring Data

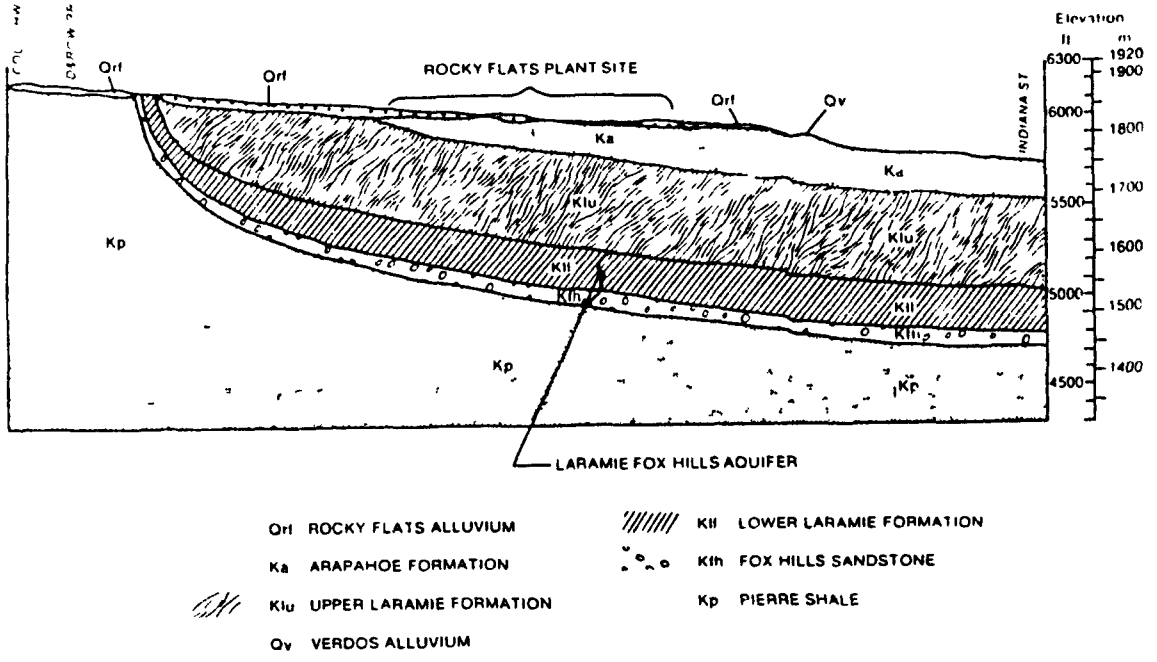


FIGURE 10 Geologic Cross-Section in the Rocky Flats Plant Area

deposits) are found in the drainages and are primarily reworked Rocky Flats Alluvium with the addition of some bedrock material The Rocky Flats Alluvium is comprised of poorly sorted Quaternary deposits of sand, gravel and cobbles within a clay matrix It has a varying thickness due to the underlying undulating bedrock surface The thickest portion occurs on the west side of the plant (up to 100 feet) and it is thinnest to nonexistent on the east edge of the plant

Bedrock at the Rocky Flats Plant is comprised of two poorly indurated fluvial formations of Cretaceous age - the Arapahoe Formation (Ka), which is immediately beneath the 384 acre security-fenced area of the plant, and the upper Laramie Formation (Klu) which underlies the west buffer zone (See Figure 10) The Arapahoe consists of fluvial claystones with interbedded discontinuous lenticular sandstones and siltstones Weathering has penetrated the bedrock 10-40 feet below the surficial material The Laramie Formation can be separated into two geological units The upper Laramie consists primarily of fluvial claystone with discontinuous thin sandstone lenses The lower Laramie is comprised of sandstones and siltstones with interbedded claystones Directly under the plant, both formations dip approximately seven degrees eastward toward the Denver Basin

Hydrogeology—There are basically two hydraulically connected ground water flow systems at the Rocky Flats Plant These occur in the Rocky Flats Alluvium and other surficial materials (including valley fill materials), and in the bedrock, primarily the claystones and sandstones of the Arapahoe Formation

5. Monitoring Data

The shallow ground water flow system occurs in the Rocky Flats Alluvium and other surficial materials under unconfined conditions This system is recharged by infiltration from incident precipitation, creeks, ponds, surface water diversion canals and spray evaporation/irrigation systems Monthly water level measurements show this system to be quite dynamic, with large fluctuations in water table elevations in response to seasonal and other stresses Large areas of little or no saturated conditions exist in the alluvial systems

Flow direction of water in the alluvial system generally follows topography, to the east and toward drainages In addition, water flow directions are controlled by the topography of the bedrock surface beneath the surficial materials Ground water discharges to the surface environment through evapotranspiration and baseflow to springs and stream channels.

The majority of the ground water movement in the Arapahoe Formation occurs in the sandstone lenses Recharge to the sandstone lenses occurs where they are in direct contact with the alluvium (subcrop areas) or by leakage through the weathered claystone Ground water flow is easterly to an area of discharge along the South Platte River, in the general area near Fort Lupton, Colorado

Sampling and Analysis

Quarterly sampling was conducted for selected pre-1986 wells and all of the wells constructed through 1986 and 1987 A total of 159 monitoring wells are currently sampled quarterly (Figure 11) Ground water quality parameters analyzed in 1988 are shown in Table 16 All of the third and fourth quarter data were not available during preparation of this report Due to the amount of data involved, only those volatile organic compounds (VOCs), inorganic compounds, metals and radionuclides most prevalent at each RCRA and CERCLA site are presented Completed analytical results for these parameters are found in the 1988 annual RCRA ground water monitoring report for regulated units at Rocky Flats Plant (RI89) and the Remedial Investigation reports for the 903 Pad and 881 Hillside areas (RI87, RI88)

The results of ground water sampling and analyses, including the range of 1988 concentrations from available data and plume migration for each of the regulated units at the Rocky Flats Plant are discussed below The areal extent of contamination is depicted by the most mobile contaminant - in most cases nitrate The location of the contaminated plumes is shown in Figure 12

Data Analysis- RCRA Units

Ground water quality data indicate that VOC and nitrate contamination exists in the alluvium of several areas The extent of plume migration for each constituent is well within the plant boundary (Figures 11 and 12) The most prevalent VOC, trichloroethylene (TCE) is present in the alluvium beneath and adjacent to the solar ponds at concentrations as high as 8,000 µg/l (For the purposes of this report, 1 µg/l is approximately equivalent to 1 ppb and 1 mg/l is approximately equivalent to 1 ppm) Nitrate concentrations

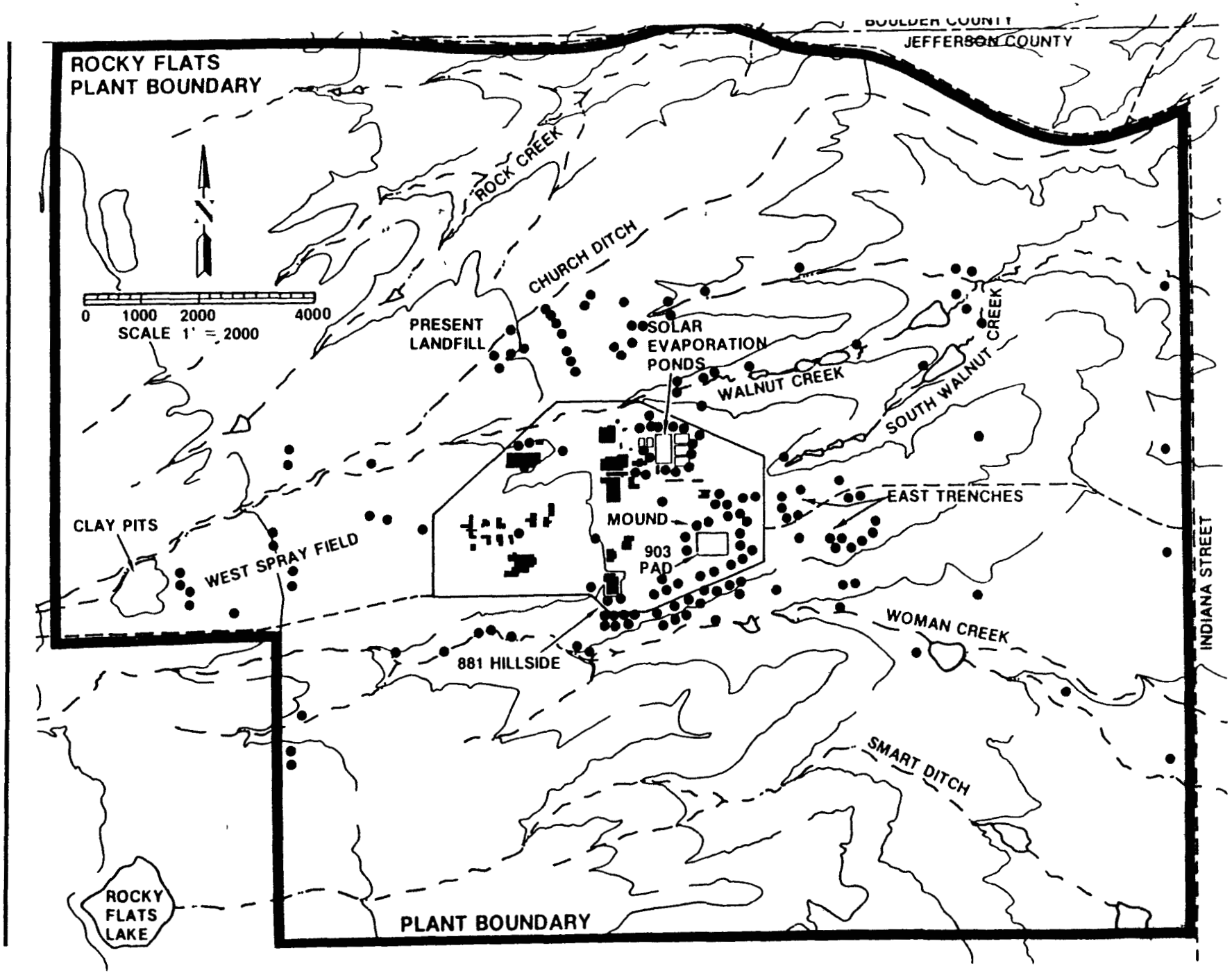


FIGURE 11 Ground Water Monitoring Wells

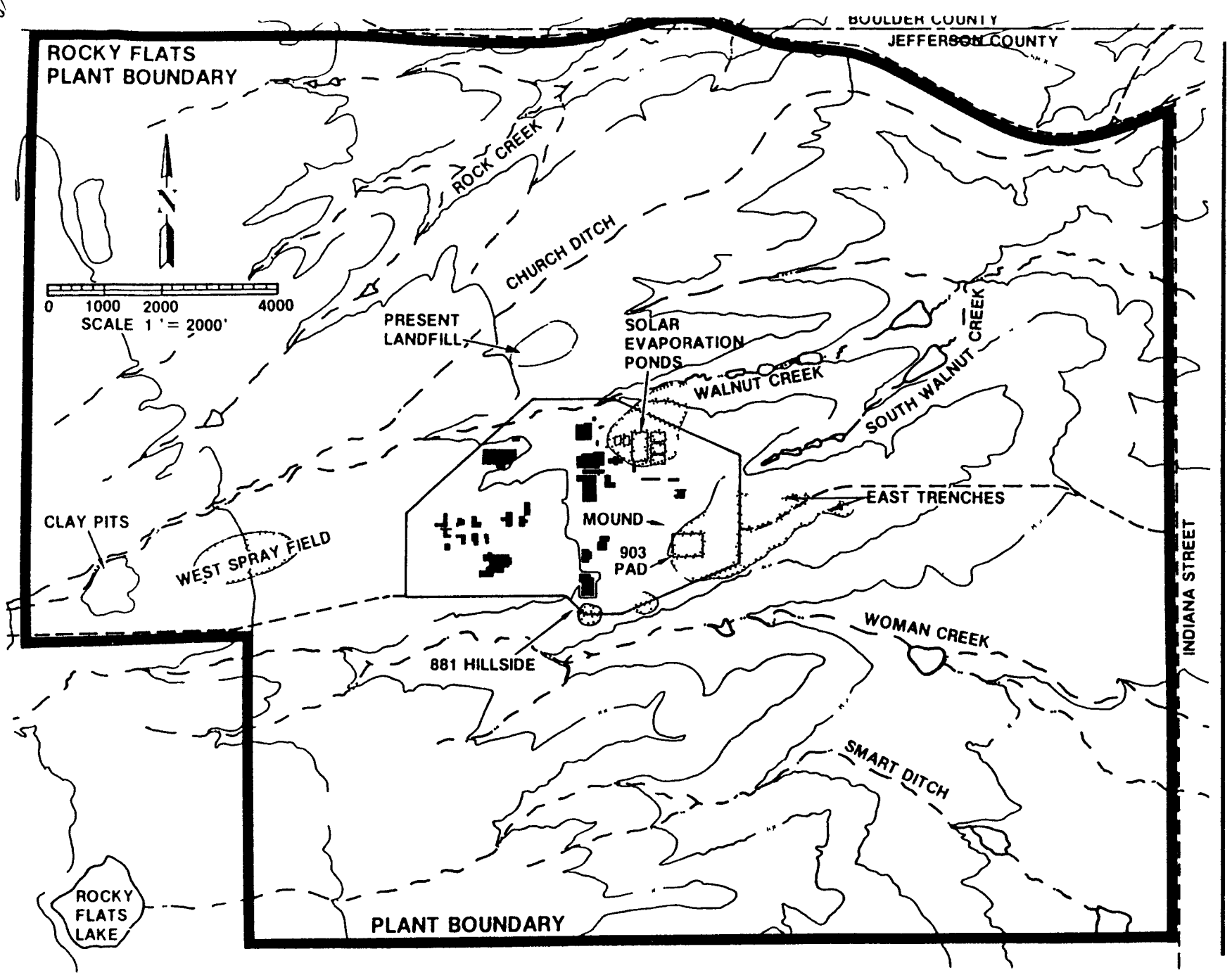


FIGURE 12 Ground Water Contamination

5. Monitoring Data

beneath and adjacent to the solar ponds ranged from a background concentration of 1 5 mg/l to 12,100 mg/l Total Uranium concentrations in the vicinity of the Solar Ponds ranged from a background concentration of 2 42 pCi/l to 358 pCi/l (8 95 x 10^{-2} Bq/l to 13 2 Bq/l) Tritium concentrations ranged from a background concentration of 593 pCi/l to 9,000 pCi/l (21 9 Bq/l to 333 Bq/l) The general pattern of higher concentrations (Figure 12) decreases rapidly away from the ponds in a north easterly direction

There are currently no conclusive indications of degradation of bedrock ground water quality by the Solar Ponds, with the exception of uranium and nitrate directly beneath the ponds (RI89)

Results of ground water quality investigations at the West Spray Field Area indicate a modest increase in above-background nitrate concentrations beneath and immediately upgradient of the unit VOCs are not present in detectable concentrations at the West Spray Fields Nitrate concentrations beneath and adjacent to the West Spray Field range from a background concentration of 1.5 mg/l to 67 mg/l Total uranium concentrations range from 0 4 to 12 8 pCi/l (1 5 X 10^{-2} Bq/l to 4 7 X 10^{-1} Bq/l) Figure 12 indicates that the higher concentrations of nitrates are within the boundaries of the West Spray Field

There is no indication of contaminant migration in the bedrock beneath or adjacent to the West Spray Field (RI89)

Results of ground water quality analyses in the area of the present Landfill indicate that the Landfill may be a source of elevated sulfate, bicarbonate and total strontium to the adjacent alluvial ground water However, the contaminant plume is largely confined within the landfill proper VOCs are not present beneath or adjacent to the present Landfill Sulfate concentrations beneath and adjacent to the present Landfill ranged from a background concentration of 27 mg/l to 4600 mg/l Strontium concentrations ranged from 0 16 mg/l to 9 46 mg/l Uranium concentrations ranged from a background concentration of 2.8 pCi/l to 7 4 pCi/l (1 05 X 10^{-1} Bq/l to 2 7 X 10^{-1} Bq/l) The extent of plume migration for the above constituents is well within the plant boundary as shown on Figure 12 A radioactive isotope of strontium (Sr-90) was analyzed for in 1987 and found to be an insignificant contributor to the total strontium concentrations

Data Analyses - CERCLA

Ground water quality data indicate that VOC contamination exists in the alluvium of each of the high priority remedial investigation (RI) areas The extent of plume migration of the major contaminants is well within the plant boundary, as indicated in Figures 11 and 12. Due to the close proximity of some areas to each other, the contamination converges in several locations Relative concentrations of the major contaminants in the three RI areas during 1988 are discussed below

At the 881 Hillside Area, the most prevalent VOC, trichloroethylene (TCE) is present at concentrations

ranging up to 15,500 µg/l Nitrate concentrations range from below detectable to 61 7 mg/l

Uranium-238 concentrations range from below detectable to 24 pCi/l (below detectable to 8 9 X 10^{1} Bq/l) Tritium concentrations are generally less than 220 pCi/l (8 1 Bq/l) Plume migration in the alluvium at the 881 Hillside Area is generally isolated at a site which was historically used for drum storage (Figure 11) Bedrock ground water in the vicinity of the 881 Hillside Area does not appear to be affected by alluvial plume migration beneath that area

Results of ground water quality analyses at the Mound and East Trenches Areas indicate moderate TCE concentrations extending eastward from the mound area to the east of the East Tenches Area (Figure 12) This plume extends to approximately 5500 feet (1700 meters) west of Indiana Street (within DOE property) TCE concentrations in this area range from below detectable to 221,860 µg/l Nitrate concentrations in this area range from less than 0 02 to 9 92 mg/l Uranium-238 concentrations range from 0 6 to 2 1 pCi/l (2 3 X 10^{-2} to 7 8 X 10^{-2} Bq/l) Tritium concentrations were all less than 220 pCi/l (8 1 Bq/l)

Bedrock ground water in the vicinity of the East Trenches appears to have an elevated concentration of VOCs, indicating a downward migration of the contaminant plume from the Mound and East Trenches Areas

Analysis of ground water quality data from the 903 pad area indicates that VOC contamination including tetrachloroethylene (PCE) and TCE contamination have a limited lateral extent in the alluvium TCE concentrations range from below detectable to 11,000 µg/l PCE concentrations range from below detectable to 212 µg/l Nitrate concentrations in the 903 Pad Area range from less than 0 02 mg/l to 5 91 mg/l Uranium-238 concentrations ranged from 0 12 to 28 pCi/l (4 4 X 10^{-3} to 1 0 Bq/l) Tritium concentrations ranged from less than 210 pCi/l to 370 pCi/l (7 8 to 14 Bq/l)

Figure 12 indicates that plume migration in the 903 Pad Area has a limited lateral extent, i e , no closer than approximately 1 6 kilometer (one-mile) from the Plant's eastern boundary Bedrock to the southwest of the 903 Pad contains elevated PCE, TCE and Uranium-238 The concentrations of VOC in the sandstones of the bedrock indicate that these sandstones are being recharged by the overlying alluvium which contains higher VOCs in the 903 Pad Area

Future Monitoring

Ground water monitoring will continue on a quarterly basis for 1989 Analytical parameters are given in Table 16 Monthly water level measurements also will continue in order to better characterize flow patterns

Additional phases of the remedial investigations for the medium priority sites will begin in 1989 Investigations for RCRA Closure activities will begin in the spring of 1989 Remedial Investigations of the low priority sites will begin in the autumn of 1989 These investigations will further assess the facility's impact on the ground water systems Feasibility studies have initiated the development and selection of effective

5. Monitoring Data

corrective action measures for the high priority areas Construction of facilities to be used for corrective actions, such as water treatment systems, currently is proposed to begin as early as the fall of 1989

F. Regional Water Monitoring

Regional water monitoring includes sampling and analysis of public water supplies and tap water from several surrounding communities However, only Great Western Reservoir and Standley Lake, of the regional water supplies, receive runoff from Rocky Flats Plant drainage systems (Figure 4) The Rocky Flats contributions to radionuclides in regional water supplies through airborne emissions were estimated in the Plant Environmental Impact Statement (US80a) These contributions were negligible compared to contributions from fallout and natural background

Water samples were collected weekly during 1988 from Great Western Reservoir, a water supply for the City of Broomfield, and from Standley Lake, a water supply for the City of Westminster and portions of the Cities of Thornton and Northglenn The weekly samples were composited into a monthly sample, and analyses were performed for plutonium, uranium, and americium concentrations Tritium analyses were conducted on weekly grab samples Annual grab samples were also collected from three regional reservoirs (Ralston, Dillon, and Boulder) and the South Boulder Diversion Canal at distances ranging from 1 6 to 96 kilometers (1 to 60 miles) from the plant These samples were collected to determine background data for plutonium, uranium, americium, and tritium in water. These data are presented in Tables 17 and 18

Drinking water from Boulder, Broomfield, and Westminster was collected weekly, preserved, composited monthly, and analyzed for plutonium, uranium, and americium Tritium analyses were performed on weekly grab samples. Quarterly grab samples of tap water were collected from the communities of Arvada, Denver, Golden, Lafayette, Louisville, and Thornton Samples were analyzed for plutonium, uranium, americium, and tritium These data are presented in Tables 17 and 18

Evaluation of the regional reservoir and drinking water data indicates no unusual trends or results The plutonium, uranium, americium, and tritium concentrations for the regional reservoirs represented a small fraction (0 4 percent or less) of the DOE Derived Concentration Guides (DCGs) The average plutonium concentration in Great Western Reservoir was 0 004 X 10^{-9} µCi/ml (1 5 X 10^{-4} Bq/l) This value is in the range of concentrations predicted for Great Western Reservoir in the Plant Environmental Impact Statement (US80a) The values given in the Environmental Impact Statement are based on known low-level plutonium concentrations in the reservoir sediments Results of the 1988 plutonium, uranium, americium, and

TABLE 17 Plutonium and Uranium Concentrations in Public Water Supplies

Location	Number of Analyses	^{C} minimum[a]	^{C} maximum[a]	^{C} mean[a]	Percent of DCG
Reservoir		**Plutonium Concentration (X 10^{-9} µCi/ml)[b]**			
Boulder	1	0 004 ± 0 029[c]	0 004 ± 0 029[c]	0 004 ± 0 029[d]	0 01
Dillon	1	-0 005 ± 0 028	-0 005 ± 0 028	-0 005 ± 0 028	0
Great Western	12	-0 003 ± 0 007	0 02 ± 0 03	0 004 ± 0 03	0 01
Ralston	1	0 025 ± 0 033	0 026 ± 0 033	0 026 ± 0 033	0 09
South Boulder Diversion Canal	1	-0 003 ± 0 028	-0 003 ± 0 028	-0 003 ± 0 028	0
Standley	12	-0 004 ± 0 006	0 06 ± 0 04	0 005 ± 0 016	0 02
Drinking Water					
Arvada	4	-0 018 ± 0 028[c]	0 10 ± 0 029[c]	-0 002 ± 0 029[d]	0
Boulder	12	-0 002 ± 0 003	0 009 ± 0 008	0 000 ± 0 011	0
Broomfield	12	-0 01 ± 0 03	0 06 ± 0 03	0 01 ± 0 02	0 03
Denver	4	-0 013 ± 0 029	0 06 ± 0 04	0 008 ± 0 03	0 03
Golden	4	-0 005 ± 0 028	0 008 ± 0 029	-0 001 ± 0 03	0
Lafayette	4	-0 012 ± 0 026	0 02 ± 0 030	-0 004 ± 0 029	0
Louisville	4	-0 005 ± 0 030	0 014 ± 0 031	0 005 ± 0 03	0 02
Thornton	4	0 002 ± 0 027	0 05 ± 0 04	0 019 ± 0 03	0 06
Westminster	12	-0 02 ± 0 03	0 018 ± 0 09	0 00 ± 0 01	0
Reservoir		**Uranium Concentration (X 10^{-9} µCi/ml)[e]**			
Boulder	1	0 4 ± 0 1[c]	0 4 ± 0 1[c]	0 4 ± 0 1[d]	0 08
Dillon	1	0 5 ± 0 1	0 5 ± 0 1	0 5 ± 0 1	0 1
Great Western	12	0 2 ± 0 1	3 6 ± 0 3	2 05 ± 0 22	0 41
Ralston	1	0 9 ± 0 1	0 9 ± 0 1	0 9 ± 0 1	0 2
South Boulder Diversion Canal	1	0 5 ± 0 1	0 5 ± 0 1	0 5 ± 0 1	0 1
Standley	12	1 0 ± 0 1	2 8 ± 0 2	1 8 ± 0 2	0 36
Drinking Water					
Arvada	4	-0 09 ± 0 09[c]	0 57 ± 0 12[c]	0 39 ± 0 14[d]	0 08
Boulder	12	-0 03 ± 0 09	0 5 ± 0 2	0 23 ± 0 11	0 05
Broomfield	12	0 5 ± 0 2	2 6 ± 0 2	1 17 ± 0 15	0 23
Denver	4	0 24 ± 0 08	1 9 ± 0 2	0 92 ± 0 14	0 18
Golden	4	0 39 ± 0 08	2 1 ± 0 2	1 12 ± 0 15	0 22
Lafayette	4	0 09 ± 0 07	0 24 ± 0 11	0 17 ± 0 09	0 03
Louisville	4	0 08 ± 0 09	0 28 ± 0 09	0 13 ± 0 12	0 03
Thornton	4	1 7 ± 0 2	3 3 ± 0 3	1 87 ± 0 21	0 37
Westminster	12	0 30 ± 0 09	1 4 ± 0 1	0 62 ± 0 13	0 12

a ^{C} minimum = minimum measured concentration, ^{C} maximum = maximum measured concentration, ^{C} mean = mean measured concentration

b Radiochemically determined as plutonium -239 and -240 The calculated Derived Concentration Guide (DCG) for plutonium in water available to members of the public is 30 X 10^{-9} µCi/ml (See Appendix A)

c Calculated as 1 96 standard deviations of the individual measurements

d Calculated as 1 96 standard deviations of the mean

e Radiochemically determined as uranium -233, -234, and -238 The calculated Derived Concentration Guide (DCG) for uranium in water available to members of the public is 500 X 10^{-9} µCi/ml (See Appendix A)

5. Monitoring Data

TABLE 18 Americium and Tritium Concentrations in Public Water Supplies

Location	Number of Analyses	^{C} minimum[a]	^{C} maximum[a]	^{C} mean[a]	Percent of DCG
Reservoir		**Americium Concentration (X 10^{-9} µCi/ml)[b]**			
Boulder	1	0 015 ± 0 026[c]	0 015 ± 0 026[c]	0 015 ± 0 026[d]	0 05
Dillon	1	-0 005 ± 0 028	-0 005 ± 0 026	-0 005 ± 0 026	0
Great Western	12	-0 004 ± 0 005	0 011 ± 0 007	0 003 ± 0 008	0 01
Ralston	1	0 002 ± 0 025	0 002 ± 0 025	0 002 ± 0 025	0 007
South Boulder Diversion Canal	1	-0 016 ± 0 022	-0 016 ± 0 022	-0 016 ± 0 022	0
Standley	12	-0 001 ± 0 006	0 02 ± 0 03	0 007 ± 0 01	0 02
Drinking Water					
Arvada	4	-0 008 ± 0 02[c]	0 018 ± 0 030[c]	0 002 ± 0 024[d]	0 007
Boulder	12	-0 002 ± 0 005	0 02 ± 0 007	0 003 ± 0 06	0 01
Broomfield	12	-0 001 ± 0 006	0 017 ± 0 008	0 006 ± 0 01	0 02
Denver	4	-0 005 ± 0 023	0 004 ± 0 025	-0 001 ± 0 03	0
Golden	4	-0 009 ± 0 02	0 003 ± 0 025	-0 004 ± 0 04	0 01
Lafayette	4	-0 014 ± 0 022	0 021 ± 0 025	-0 002 ± 0 02	0
Louisville	4	0 016 ± 0 022	-0 005 ± 0 023	-0 009 ± 0 02	0
Thornton	4	0 000 ± 0 024	0 060 ± 0 032	0 026 ± 0 02	0 09
Westminster	12	-0 004 ± 0 005	0 025 ± 0 008	0 005 ± 0 006	0 02
Reservoir		**Tritium Concentration (X 10^{-9} µCi/ml)[e]**			
Boulder	f				
Dillon	1	227 ± 521[c]	227 ± 521[c]	227 ± 521[d]	0 01
Great Western	48	-960 ± 280	730 ± 590	-30 ± 120	0
Ralston	f				
South Boulder Diversion Canal	f				
Standley	48	-740 ± 290	1380 ± 520	10 ± 130	0 0005
Drinking Water					
Arvada	4	-340 ± 260[c]	310 ± 540[c]	-30 ± 420[d]	0
Boulder	12	-610 ± 530	600 ± 600	-20 ± 130	0
Broomfield	12	-500 ± 420	640 ± 610	-20 ± 120	0
Denver	4	-410 ± 520	10 ± 520	-230 ± 420	0
Golden	4	-400 ± 260	300 ± 540	-50 ± 420	0
Lafayette	4	-250 ± 260	30 ± 300	-60 ± 420	0
Louisville	4	-280 ± 520	90 ± 520	-130 ± 420	0
Thornton	4	-300 ± 260	150 ± 530	-50 ± 420	0
Westminster	12	-700 ± 290	740 ± 600	10 ± 130	0 0005

a ^{C} minimum = minimum measured concentration, ^{C} maximum = maximum measured concentration, ^{C} mean = mean measured concentration

b Radiochemically determined as americium 241 The interim standard calculated Derived Concentration Guide (DCG) for americium in water available to members of the public is 30 X 10^{9} µCi/ml (See Appendix A)

c Calculated as 1 96 standard deviations of the individual measurements

d Calculated as 1 96 standard deviations of the mean

e The interim standard calculated Derived Concentration Guide (DCG) for tritium in water available to members of the public is 2,000,000 X 10^{9} µCi/ml (See Appendix A)

f Not analyzed

tritium data for drinking water in nine communities were within the background range All drinking water values were 0 37 percent or less of the applicable DCG

Drinking water standards have been adopted by the State of Colorado (CO77, CO81) and the Environmental Protection Agency (EPA) (US76a) for alpha-emitting radionuclides (excluding uranium and radon) and for tritium These standards are 15 X 10^{-9} µCi/ml and 20,000 X 10^{-9} µCi/ml (5.55 X 10^{-1} Bq/l and 740 Bq/l) respectively During 1988, the sum of the average concentrations of plutonium and americium (alpha-emitting radionuclides) for each community tap water location was 0 045 X 10^{-9} µCi/ml (1 7 X 10^{-3} Bq/l) or less This value is 0.3 percent or less of the State of Colorado and EPA drinking water standards for alpha activity The average tritium concentration in Great Western Reservoir, Standley Lake, and in all community tap water samples was 10 X 10^{-9} µCi/ml (3 7 X 10^{-1} Bq/l) or less That value is typical of background tritium concentrations in Colorado and represents less than one percent of the State of Colorado and EPA drinking water standard for tritium (CO81, US76a)

G. Soil Sampling and Analysis

Forty soil samples were collected in October 1988 at radial intervals of approximate distances of 1 6 and 3 2 kilometers (1 and 2 miles) from the center of the plant The soil samples were collected by driving a 10 X 10 centimeter (4 X 4 inches) cutting tool 5 centimeters (2 inches) into undisturbed soil (RO88) The soil sample within the tool cavity was collected and placed into a new one-gallon metal can Five sub-samples were collected from the corners and center of two one-meter squares, which were spaced one meter apart Each set of ten subsamples was composited for the plutonium radiochemical analysis

The 1988 soil plutonium data are summarized in Table 19 and displayed on Figure 13 The concentrations of soil plutonium at the 1 6 kilometer (1 mile) distance from the plant center ranged from 0 02 to 10 6 pCi/g (0 74 to 391 Bq/kg) The concentrations of soil plutonium for the 3 2 kilometer (2 mile) samples ranged from 0 02 to 7 12 pCi/g (0 74 to 263 Bq/kg) The maximum plutonium values were found in the soil samples from the eastern portion of the 6550 acre buffer zone These sample locations are east and southeast (generally downwind) of the major source of plutonium contamination, the 903 Pad Area The plutonium concentrations measured in 1988 were similar to the values measured since 1984 Data for 1985, 1986 and 1987 are included in Table 19 for comparison Figure 14 has been included to identify the sampling locations by number Variability in concentrations from year to year for sampling at the same site is to be expected Samples are collected from the area around a sampling location, never more than 100 feet from the located sampling point To sample the same location exactly from year to year is not desirable, since that location

5. Monitoring Data

Table 19 Plutonium Concentration[a] in Rocky Flats Area Soil Samples[b] at One and Two Miles from the Plant Center, 1985-1988

Location	1985 Pu(pCi/g)[c]	1986 Pu (pCi/g)[c]	1987 Pu (pCi/g)[c]	1988 Pu (pCi/g)[c]
1-018	0 15 ± 0 02[d]	0 15 ± 0 02	0 18 ± 0 02	0 10 ± 0 01
1-036	0 08 ± 0 01	0 10 ± 0 02	0 06 ± 0 01	0 88 ± 0 01
1-054	0 02 ± 0 01	0 04 ± 0 01	0 04 ± 0 01	0 03 ± 0 01
1-072	0 32 ± 0 03	0 63 ± 0 06	0.51 ± 0 05	0.37 ± 0 04
1-090	1 0 ± 0 09	7 4 ± 0 62	7 05 ± 0 77	10 6 ± 0 98
1-108	13 0 ± 1 3	15 0 ± 1 4	2 37 ± 0 21	10 4 ± 0 94
1-126	1 9 ± 0 17	1 9 ± 0 18	2 75 ± 0 28	1.55 ± 0 14
1-144	0 32 ± 0 03	0 27 ± 0 02	0 36 ± 0 04	0 20 ± 0 02
1-162	0 10 ± 0 01	0 08 ± 0 01	0 17 ± 0 02	0 09 ± 0 01
1-180	0 06 ± 0 01	0 06 ± 0 01	0 10 ± 0 01	0 06 ± 0 01
1-198	0 16 ± 0 02	0 16 ± 0 02	0 21 ± 0 02	0 10 ± 0 01
1-216	0 05 ± 0 01	0 10 ± 0 01	0 16 ± 0 02	0 05 ± 0 01
1-234	0 05 ± 0 01	0 04 ± 0 01	0 05 ± 0 01	0 05 ± 0 01
1-252	0 14 ± 0 02	0 11 ± 0 01	0 21 ± 0 03	0 09 ± 0 01
1-270	0 07 ± 0 01	0 08 ± 0 01	0 09 ± 0 01	0 07 ± 0 01
1-288	0 05 ± 0 01	0 05 ± 0 01	0 06 ± 0 01	0 03 ± 0 01
1-306	0 09 ± 0 01	0 17 ± 0 02	0 21 ± 0 03	0 12 ± 0 01
1-324	0 15 ± 0 02	0 21 ± 0 02	0 24 ± 0 03	0 16 ± 0 02
1-342	0 02 ± 0 01	0 03 ± 0 01	0 03 ± 0 01	0 02 ± 0 01
1-360	0 11 ± 0 01	0 19 ± 0 02	0 16 ± 0 02	0 12 ± 0 02
2-018	0 04 ± 0 01	0 03 ± 0 01	0 04 ± 0 01	0 02 ± 0 00
2-036	0 02 ± 0 01	0 07 ± 0 01	0 10 ± 0 01	0 07 ± 0 01
2-054	0 03 ± 0 01	0 05 ± 0 01	0 10 ± 0 01	0 03 ± 0 01
2-072	0 33 ± 0 03	0 23 ± 0 02	0 36 ± 0 04	0 11 ± 0 01
2-090	2.5 ± 0 25	5 3 ± 0 48	4 48 ± 0 52	7.12 ± 0 67
2-108	0 41 ± 0 04	0 46 ± 0 04	0.57 ± 0 06	0 47 ± 0 05
2-126	0 42 ± 0 04	0 44 ± 0 05	0 40 ± 0 04	0 03 ± 0 01
2-144	0 04 ± 0 01	0 04 ± 0 01	0 08 ± 0 01	0 35 ± 0 03
2-162	0 01 ± 0 00	0 02 ± 0 01	0 03 ± 0 01	0 02 ± 0 01
2-180	0 11 ± 0 01	0 04 ± 0 01	0 03 ± 0 01	0 03 ± 0 01
2-198	0 02 ± 0 01	0 08 ± 0 01	0 14 ± 0 02	0 10 ± 0 01
2-216	0 04 ± 0 01	0 06 ± 0 01	0 07 ± 0 01	0 07 ± 0 01
2-234	0 05 ± 0 01	0 05 ± 0 01	0 07 ± 0 01	0 03 ± 0 01
2-252	0 04 ± 0 01	0 07 ± 0 01	0 06 ± 0 01'	0 04 ± 0 01
2-270	0 04 ± 0 01	0 06 ± 0 01	0 08 ± 0 01	0 06 ± 0 01
2-288	0 04 ± 0 01	0 05 ± 0 01	0 13 ± 0 02	0 07 ± 0 01
2-306	0 06 ± 0 01	0 02 ± 0 01	0 08 ± 0 01	0 02 ± 0 00
2-324	0 04 ± 0 01	0 09 ± 0 01	0 08 ± 0 01	0 14 ± 0 02
2-342	0 13 ± 0 01	0 12 ± 0 01	0 14 ± 0 02	0 10 ± 0 01
2-360	0 09 ± 0 01	0 05 ± 0 01	0 08 ± 0 01	0 05 ± 0 01

a Not blank corrected
b Sampled to a depth of 5 cm
c Concentrations are for the fraction of soil measuring less than 2mm in diameter
d Error term represents 2 standard deviations

would have been disturbed by the previous years sampling Since the sampling from year to year is from slightly different locations, the effects of non-uniform deposition by wind, redistribution of plutonium by erosion or faunal activities, and sampling and analytical error will all contribute to variability

Soil Sample Collection

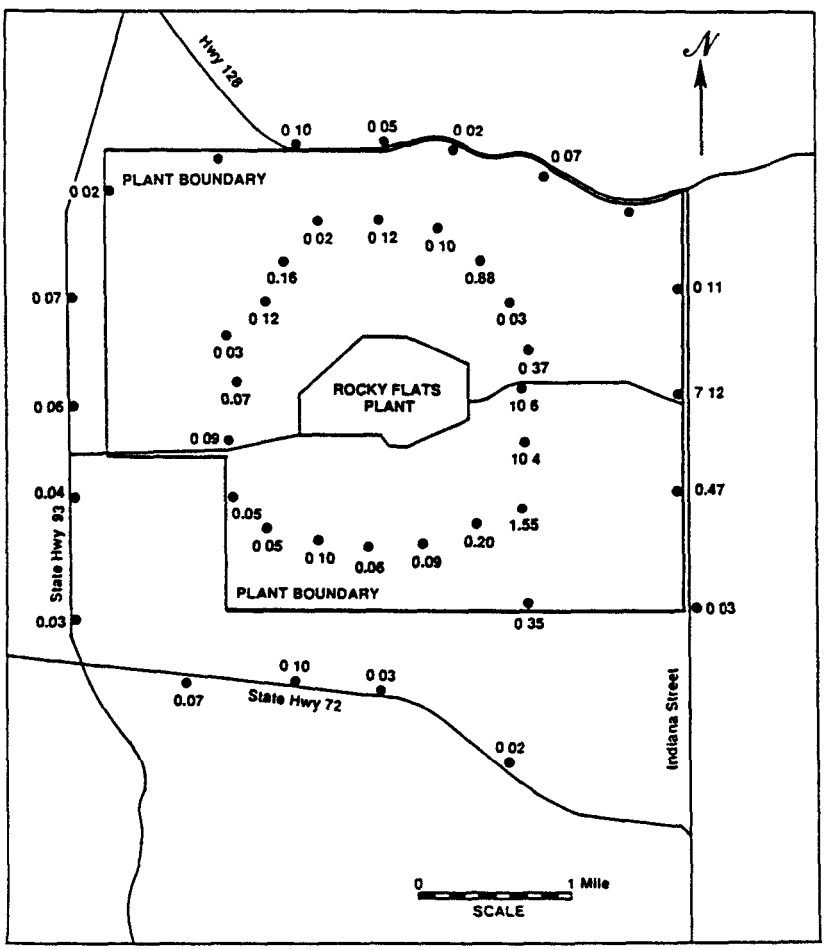


FIGURE 13 Plutonium Concentrations in Soil
(Values in Picocuries Per Gram)

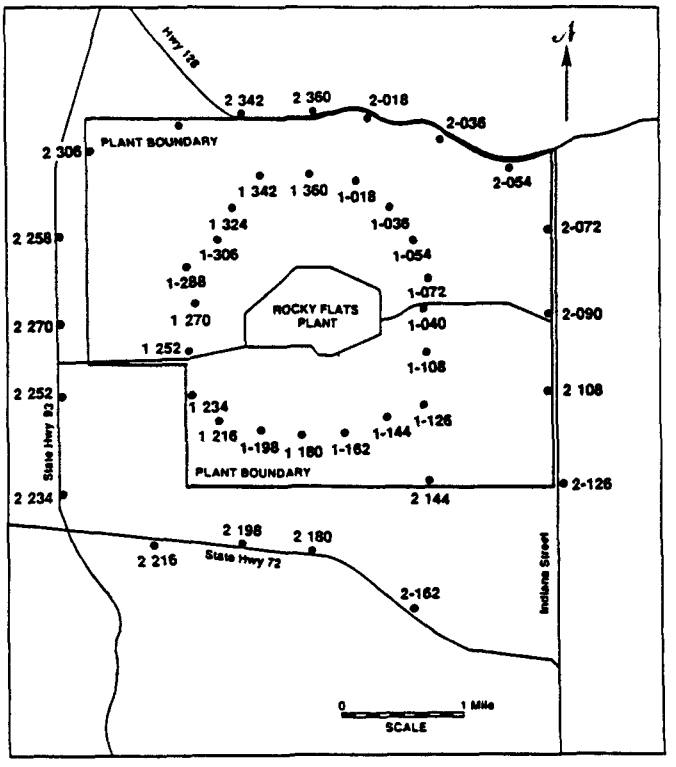


FIGURE 14 Soil Sampling Locations

H. External Gamma Radiation Dose Monitoring

Thermoluminescent dosimeters (TLDs) are used to measure external penetrating gamma radiation exposure at 46 locations on and off the plantsite Replicate TLDS are located at each site All TLDs are environmentally exposed for three months The TLDs are placed at 18 locations within the 384 acre property enclosed by the security fence Measurements are also made at 16 perimeter locations three to six kilometers (two to four miles) from the plant and in 12 communities located within 50 kilometers (30 miles) of the plant The TLDs are placed at a height of one meter (three feet) above ground level.

During 1983, conversion from a Harshaw TLD system to a Panasonic system was initiated For one complete calendar year, two TLDs of each type were used at each monitoring location Beginning in 1984, only the Panasonic TLDs were used

The environmental TLDs consist of two Panasonic 802 dosimeters, each of which has four elements Only one

TABLE 20 Environmental Thermoluminescent Dosimeter Measurements

Location Category	Number of Locations	Number of Measurements	Mean Annual Measured Dose (mrem)	95% Confidence Interval on the Mean (mrem)[a]	95% Confidence Interval on an Individual Measurement (mrem)[b]
Onsite	18	109	154	± 4	± 47
Perimeter	16	87	128	± 2	± 19
Community	12	68	155	± 4	± 37

a Calculated as 1 96 standard deviations of the mean
b Calculated as 1 96 standard deviations of the individual measurements

of the elements of each dosimeter is used This element consists of calcium sulfate, thulium drifted ($CaSO_4$ Tm) deposited on a polymid surface The phosphor is covered with a clear teflon, and backed with an opaque ABS plastic The TLDs are packaged in a small plastic bag, a paper envelope, and another plastic bag to protect them from the weather Total filtration over the phosphor is 178.5 mg/cm^2

The environmental dosimeters have been individually calibrated (three times each) against an onsite Cs-137 gamma calibration source Calibration linearity studies have confirmed that TLD response is linear for exposure levels ranging from 10 mrem to 1000 mrem The mean calibration factor for each dosimeter is applied to measurements taken with that dosimeter An additional correction is applied to correct for day to day variations in reader calibration

It was determined that a statistically significant (p=0 05) difference in response exists between the Harshaw environmental monitoring system used prior to 1984, and the Panasonic environmental monitoring systems used beginning in 1984 In order to compare the 1988 values with the previously reported Harshaw data, it is necessary to multiply the Panasonic results given in Table 20 by 1 046

The annual dose equivalent for each location category was calculated by determining the average mrem/day for each of the three categories using data from the four quarters in 1988 These values were then multiplied by 365 25 to obtain yearly totals

In previous Annual Reports, the Annual Measured Dose was reported with a 95 percent confidence interval on the mean using the standard error of the mean,

calculated from the variance of the individual measured values Beginning in 1985, the 95 percent confidence interval on an individual observation within each location category - calculated as 1 96 standard deviations - was added to the report This latter interval may be used for assessing the variability of the individual location measurements within a location category

The 1988 environmental measurements using TLDs are summarized in Table 20 The average annual dose equivalents, as measured onsite, in the perimeter environs, and in communities, were 154, 128, and 155 mrem (1.54 1 28, and 1.55 mSv), respectively These values are indicative of background gamma radiation in the area

6
ASSESSMENT OF POTENTIAL PLANT CONTRIBUTION TO PUBLIC RADIATION DOSE

In August 1985, the Department of Energy (DOE) adopted an interim radiation protection standard for DOE environmental activities to be implemented in CY1985 (Va85) This interim standard incorporates guidance from the National Council on Radiation Protection and Measurements (NCRP), as well as the Environmental Protection Agency Clean Air Act air emission standards as implemented in 40 CFR 61, Subpart H (US83, US85) Included in the interim standard is a revision of the radiation dose limits for protection of the public for DOE facilities In July, 1988, DOE published radiation dose conversion factors to be used for calculating dose from intakes of radioactive materials and from exposure to external penetrating radiation resulting from air and water immersion and ground deposition (US88a, US88b) The internal dose factors are based on the International Commission on Radiological Protection (ICRP) Publications 30 and 48 methodology for radiation dosimetry The DOE interim standard and the dose conversion factor tables have been used in this 1988 "Annual Site Environmental Monitoring Report" for assessment of the potential Rocky Flats Plant contribution to public radiation dose As in past Annual Reports, the dose limits and dose conversion factors used are specified, and comparisons can be made with information in past Annual Reports to determine the magnitude of the changes

Potential public radiation dose commitments, which could have resulted from plant operations, were calculated from average radionuclide concentrations measured at the DOE property boundary and in surrounding communities Inhalation, water ingestion, and - to a much lesser extent - ground-plane irradiation are the principal pathways of exposure Swimming and consumption of foodstuffs are insignificant pathways This latter finding is to be expected because of limited swimming and fishing in the area and because most locally consumed food is produced at considerable distances from the plant

The dose assessment for 1988 was conducted for several locations the Rocky Flats Plant property (site) boundary, nearby communities, and sites to a distance of 80 kilometers (50 miles) Dose conversion factors

6. Assessment of Potential Plant Contribution to Public Radiation Dose

used for the inhalation and water ingestion, and ground-plane irradiation pathways were from the tables provided by DOE (US88a, US88b) The relative abundances of plutonium and americium isotopes in plutonium used at Rocky Flats Plant (shown in Table 21) were used to calculate composite dose conversion factors for plutonium The fractions of ingested radionuclides that are absorbed from the gastro-intestinal tract and the lung clearance classes for inhaled radionuclides were chosen to maximize the associated dose conversion factors The inhalation rate of 2 66 x 10^{-4} m^3/s and the water ingestion rate of 2 liters (2 1 quarts) per day were derived from data for the ICRP reference man and were included in the factors (In75) Each of these dose conversion factors is for a 50-year dose commitment from one year of chronic exposure The dose conversion factors used in this report are listed in Table 22

A. Dose Assessment Source Terms

Plutonium and americium in the Rocky Flats environs are the combined result of residual fallout deposition from global atmospheric nuclear weapons testing and past releases from the plant Uranium, a naturally occurring element, is indigenous to many parts of Colorado and also is used in plant operations in vari-

TABLE 21 Isotopic Composition of Plutonium Used at Rocky FlatsPlant (US80a)

Isotope	Relative Weight (Percent)	Specific Activity (Ci/g)	Relative Activity[a] (Ci/g)	Fraction of Pu Alpha Activity[b]
Pu-238	0 01	17 1	0 00171	0 0233
Pu-239	93 79	0 0622	0 05834	0 7962
Pu-240	5 80	0 228	0 01322	0 1804
Pu-241	0 36	103 5*	0 37260*	5 085*
Pu-242	0 03	0 00393	1 18 x 10^{-6}	1 61 x10^{-5}
Am-241	-	-	-	0 20[c]

* Beta Activity

a Obtained by multiplying the percent by weight by the specific activity
b Obtained by dividing the relative activity by the sum of the relative activities for the plutonium alpha emitters
c The value for Am-241 is taken to be 20% of the plutonium alpha activity

Table 22 Dose Conversion Factors Used in Dose Assessment Calculations

Inhalation $\left\{\frac{\text{rem}}{\text{microcurie}}\right\}$ [a,b]

Organ	Pu-239, -240
Effective Dose Equivalent	5.71×10^{12}
Liver	2.22×10^{13}
Bone Surfaces	1.04×10^{14}
Lung	1.08×10^{13}

Water Ingestion $\left\{\frac{\text{rem}}{\text{microcurie}}\right\}$ [a,c]

Organ	Pu-239, -240	Am-241	U-233, -234, -238
Effective Dose Equivalent	3.53×10^{6}	3.29×10^{6}	1.90×10^{5}
Liver	1.32×10^{7}	1.24×10^{7}	(e)
Bone Surfaces	6.42×10^{7}	5.91×10^{7}	2.99×10^{6}
Lung	(f)	(f)	(f)

Ground-Plane Irradiation $\left\{\frac{\text{rem square meter}}{\text{microcurie}}\right\}$ [d]

Organ	Pu-239, -240	Am-241
Effective Dose Equivalent	4.80×10^{-5}	2.99×10^{-3}
Liver	4.53×10^{-6}	1.78×10^{-3}
Bone Surfaces	1.62×10^{-5}	3.69×10^{-3}
Lung	9.78×10^{-6}	2.01×10^{-3}

a Inhalation and water ingestion dose conversion factors were adopted from DOE/EH-0071 (US88b) and are for a 50-year dose commitment period and a 1 µm Activity Median Aerodynamic Diameter (AMAD) particle size (VA85) GI absorption fractions and lung clearance classes were chosen to maximize the dose conversion factors

b An inhalation rate of 2.66×10^{2} ml/s for 1 year was assumed

c A water intake rate of 2×10^{3} ml (2.1 quarts) per day for 1 year was assumed

d Ground plane irradiation dose conversion factors were adopted from DOE/EH-0070 (US88a) For Pu-239, -240, the higher of the factors for the two isotopes was used

e The liver recieves no significant dose from this pathway

f The lung receives no significant dose from this pathway

6. Assessment of Potential Plant Contribution to Public Radiation Dose

ous isotopic ratios Tritium, a radionuclide formed by natural processes, also is associated with plant operations

Inhalation source terms for the 1988 dose assessment were based on plutonium-239 and -240 concentrations measured in ambient air samples Although it is known that much of this plutonium in air is from residual fallout from past global atmospheric weapons testing, for the purpose of this dose assessment it was conservatively assumed that all of the plutonium originated from the Rocky Flats Plant The ingestion source terms were based on measured concentrations of plutonium, americium, uranium, and tritium in water The ground-plane source terms were based on measured values of plutonium in soil and an assumed ratio of 0 20 for the americium to plutonium alpha activity in the soil This ratio is the maximum level of americium in-growth from Rocky Flats plutonium (US80a)

The maximum site-boundary dose assessment assumes that an individual is continuously present at the plant perimeter, which actually is uninhabited The plutonium inhalation source term of $1\ 0 \times 10^{-17}$ µCi/ml ($3\ 7 \times 10^{-7}$ Bq/m^3) was the maximum annual average concentration of plutonium-239 and -240, as measured for a single location in the perimeter ambient air sampling network

The water supply for the individual at the site boundary was assumed to be Walnut Creek, which intermittently flows offsite and provides the liquid effluent source term at the site boundary During 1988, the plutonium concentration in Walnut Creek averaged 1×10^{-11} µCi/ml (4×10^{-4} Bq/l) The average americium concentration was 1×10^{-11} µCi/ml (4×10^{-4} Bq/l) These concentrations were used as the water ingestion source term for the maximum site boundary dose assessment The average concentration of uranium in Walnut Creek was $4\ 8 \times 10^{-9}$ µCi/ml ($1\ 8 \times 10^{-1}$ Bq/l) while the average concentration in incoming raw water was $1\ 6 \times 10^{-9}$ µCi/ml ($5\ 9 \times 10^{-2}$ Bq/l) The source term for uranium ingestion was the difference between these two values [3.2×10^{-9} µCi/ml ($1\ 2 \times 10^{-1}$ Bq/l)] The average tritium concentration in Walnut Creek was less than zero and within the background range typically measured in regional waters This concentration of tritium is an insignificant contributor to dose Tritium in the water was, therefore, omitted from the 1988 dose assessment

The ground-plane irradiation source term is based on the maximum plutonium in soil deposition at the plant perimeter, as reported by the Environmental Measurements Laboratory (US70) This source term is 3×10^{-2} µCi/m^2 (1×10^3 Bq/m^2) The americium is assumed to be present at an alpha activity level of 20 percent of that of the plutonium, which is the maximum quantity of americium that can be present in Rocky Flats plutonium from the decay of plutonium-241 (US80a) The americium source term, therefore, is conservatively estimated to be 6×10^{-3} µCi/m^2 (2×10^2 Bq/m^2)

TABLE 23 Radioactivity Concentrations Used for 1988 Dose Calculations

	Air (μCi/ml)	Water (μCi/ml)			Surface Deposition (μCi/m^2)	
Location	Pu-239,-240	Pu-239,-240	Am-241	U-233,-234, -238	Pu-239,-240	Am-241
Maximum Site Boundary	1.0×10^{-17}	1.0×10^{-11}	1.0×10^{-11}	3.2×10^{-9}	3×10^{-2}	6×10^{-3}
Community	5.0×10^{-18}	-	-	-	-	-

Source terms and corresponding dose commitments were evaluated for each of the surrounding communities to determine the maximum community exposure Ground-plane irradiation and water ingestion pathways were insignificant for all of the communities The only significant pathway for radiation exposure was inhalation of plutonium in air The source term for inhalation used in the dose assessment was the maximum annual average plutonium concentration measured in community ambient air [5.0×10^{-18} μCi/ml (1.9×10^{-7} Bq/m^3)] This concentration was the annual average concentration measured for the Superior ambient air sampler

A summary of the source terms for the maximum site boundary and for community locations is tabulated in Table 23

B. Maximum Site Boundary Dose

The maximum dose to an individual continuously present at the site boundary is based on the radionuclide concentrations shown in Table 23. From these concentrations and the dose conversion factors in Table 22, a 50-year dose commitment of 7.5×10^{-4} rem (7.5×10^{-6} Sv) is calculated as the effective dose equivalent from all pathways The corresponding bone surfaces dose is 1.2×10^{-2} rem (1.2×10^{-4} Sv) The Department of Energy (DOE) interim radiation protection standard for members of the public for prolonged periods of exposure is 0.1 rem per year (1×10^{-3} Sv per year) effective dose equivalent The interim standard for the air pathway only is 7.5×10^{-2} rem per year (7.5×10^{-4}

6. Assessment of Potential Plant Contribution to Public Radiation Dose

Sv per year) for any organ for internally deposited radionuclides (VA85) The maximum site boundary dose represents 0 75 percent of the standard for all pathways for the effective dose equivalent If all of the dose were received from the air pathway, it would represent 16 percent of the air emission standard for any organ

C. Maximum Community Dose

Based on radionuclide concentrations in surrounding communities (Table 23), the calculated 50-year dose commitments are $2\,9 \times 10^{-5}$ rem ($2\,9 \times 10^{-7}$ Sv) effective dose equivalent and $5\,2 \times 10^{-4}$ rem ($5\,2 \times 10^{-6}$ Sv) to bone surfaces These values represent less than 0 03 percent of the DOE interim standard for effective dose equivalent and 0 69 percent of the air emission standard for any organ

The maximum site boundary and community 50-year committed dose equivalents are summarized in Table 24 The effective dose equivalents may be compared to an average annual effective dose equivalent for the Denver area of about 3.5×10^{-1} rem ($3\,5 \times 10^{-3}$ Sv) from natural background radiation (NA87) (See Table 25) This natural background radiation level for Denver is higher than that shown for the total body in past Annual Reports prior to 1985 and also higher than that shown for effective dose equivalent in the 1985 and 1986 Annual Reports The level reflects the most recent assessment of natural background radiation exposure of the population of the United States by the National Council on Radiation Protection and Measurements (NCRP) (NA87) It includes the significant contribution to effective dose equivalent from inhaled indoor radon, as well as the adoption of the ICRP 30 methodology of radiation dosimetry The cosmic radiation and external primordial nuclides sources shown in Table 25 reflect the regional dose levels for the Denver

TABLE 24 Fifty-Year Committed Dose Equivalent From One Year of Chronic Intake/Exposure

Source	Effective Dose Equivalent (rem)	Liver (rem)	Bone Surfaces (rem)	Lung (rem)
Maximum Site Boundary Location	$7\,5 \times 10^{-4}$	$4\,9 \times 10^{-4}$	$1\,2 \times 10^{-2}$	$1\,2 \times 10^{-4}$
Community	$2\,9 \times 10^{-5}$	$1\,1 \times 10^{-4}$	$5\,2 \times 10^{-4}$	$5\,4 \times 10^{-5}$

area which result from Denver's higher elevation and greater concentrations of naturally-occurring radioactive materials in soil The internal primordial nuclides source includes the average dose from indoor radon estimated by the NCRP for the entire United States Investigations are now being conducted to determine any regional differences in indoor radon doses that may exist Once these studies are completed, the estimates of natural background radiation dose for the Denver area may be modified again to reflect indoor radon doses that are specific to this region

D. Eighty-Kilometer Dose Estimates

The dose commitment for all individuals, to a distance of 80 kilometers (50 miles), is based on the calculated maximum community dose estimates shown in Table 24 The estimated committed effective dose equivalent is less than 1×10^{-3} rem or 1 mrem (1×10^{-5} Sv) A level of "1 mrem/yr" or less is specified as a *de minimis* (inconsequential) level of exposure in the DOE Guide entitled, "A Guide to Reducing Radiation Exposure to As Low As Reasonably Achievable (ALARA) " (US80b) The Guide further states

> "Radiation-induced mutations and diseases have not been discovered in populations that are or have been exposed to doses of 100 mrem/year or less Hence, it is reasonable to suggest that no health effects will be discerned if a population is exposed to an additional 1 percent of the level, i e , 1 mrem/yr An annual dose of 1 mrem should be regarded as a level which is clearly *de minimis* "

Based on the *de minimis* concept in the Guide and on the maximum community dose estimates, the dose commitment for all individuals to 80 kilometers is considered to be *de minimis*

The Environmental Protection Agency (EPA) requires that approved EPA procedures be used to demonstrate compliance with its radioactivity air emissions standards found in 40 CFR 61, Subpart H (US85) At the writing of this Report, the only procedure for which the EPA has published approval is modeling of radioactivity air emissions data using the AIRDOS-EPA atmospheric dispersion/radiation dose calculation computer code. (US85) The Rocky Flats Plant is seeking EPA approval for using environmental (ambient) sampling as the basis for demonstrating compliance with 40 CFR 61, Subpart H This is the procedure that is described above for calculating projected radiation doses to the public Pending EPA approval of this procedure, the AIRDOS-EPA computer code also has been used to calculate projected radiation doses to the public as a result of air emissions of radioactive materials from the Rocky Flats Plant The results of this

6. Assessment of Potential Plant Contribution to Public Radiation Dose

computer code calculation independently confirm that the maximum radiation dose to a member of the public as a result of exposure to airborne radioactivity from the Rocky Flats Plant in 1988 is less than 1 mrem effective dose equivalent

TABLE 25 Estimated Annual Natural Background RadiationDose for the Denver Metropolitan Area (NA87)

Source	Effective Dose Equivalent (rem)
Cosmic Radiation	0 050
Cosmogenic Nuclides	0 001
Primordial Nuclides-External	0 063
Primordial Nuclides-Internal	0 239
Total for One Year (rounded)	0 35

APPENDIX A
APPLICABLE GUIDES AND STANDARDS

The Rocky Flats Plant Environmental Monitoring Program evaluates plant compliance with all applicable guides, limits, and standards. Guide values and standards for radionuclides in ambient air and waterborne effluents have been adopted by the Department of Energy (DOE), the Colorado Department of Health, and (for the air pathway only) by the Environmental Protection Agency (EPA) (VA85, CO78, US85) The guides are based on recommendations published by the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) Ambient air data for nonradioactive parameters has been collected at Rocky Flats for comparison to the criteria pollutants listed under the EPA National Ambient Air Quality Standards, established by the Clean Air Act. (US81b) Instrumentation and methodology follow requirements established by EPA in the Quality Assurance Handbook for Air Pollution Measurement Systems (US76b) Limits for nonradioactive pollutants in effluent water have been defined by an EPA National Pollutant Discharge Elimination System (NPDES) discharge permit (US84a) In 1976, the EPA also established standards for radionuclides in drinking water (US76a) These drinking water standards have been adopted, in turn, by the State of Colorado (CO77, CO81) In 1973, Colorado first enacted the Colorado Water Quality Control Act (CO73) Standards for implementation of this Act were first enacted in 1974 and currently include provisions for protection of Colorado waterways from both radioactive and non-radioactive contaminants (CO87)

In a memorandum of August 5, 1985, the DOE adopted an interim radiation protection standard for DOE environmental activities to be implemented in CY 1985 (VA85) This interim standard incorporates guidance from the NCRP, as well as the EPA Clean Air Act air emission standards for radioactive emissions, as implemented in 40 CFR 61, Subpart H (US83, US85) Included in the interim standard is a revision of the dose limits for members of the public Table A-1 summarizes the interim radiation dose limits for members of the public. Tables of radiation dose conversion factors to be used for calculating dose from intakes of radioactive materials were published by DOE in July, 1988 (US88a, US88b) The dose factors are based on ICRP Publications 30 and 48 methodology for radiation dosimetry Effluent air and water Derived Concentration Guides are secondary guides derived from the primary dose standards and were calculated using dose conversion factors and assumed air and water intake rates The calculated Derived Concentration Guides (DCGs) are based on the interim standard dose limit for all pathways of 0 1 rem/year for a 50-year committed effective dose equivalent The dose

Appendix A
Applicable Guides and Standards

conversion factors provided in the DOE publications were used and intake rates of 8400 cubic meters per year (2.66×10^{-4} m^3/s) for air and 730 liters per year (2 l/d) for water as prescribed by the DOE Guidance were assumed for the calculations. (US88b) The DCGs are given in Table A-2 and are comparable in concept to the Radioactivity Concentration Guides (RCGs) published by DOE for its previous radiation protection standard given in DOE Order 5480.1A, Chapter XI (US81a)

The previous RCGs included permissible concentrations of specific radionuclides and mixtures of radionuclides in air (RCG_a) and water (RCG_w) for individuals in the general population (US81a) In addition to restricting specific radionuclides, the guides restricted the concentration of radionuclides in a mixture such that the sum of the ratios of each radionuclide concentration to the appropriate concentration guide would not exceed a value of one The guides further stated that a radionuclide might be considered as not present in a mixture if (a) the ratio of the concentration of that radionuclide in the mixture to the concentration guide for that radionuclide did not exceed one tenth and (b) the sum of such ratios for all radionuclides considered as not present in the mixture did not exceed one fourth

During 1988, average specific radionuclide concentrations in air and water for the Rocky Flats Plant were all less than one tenth of the appropriate Derived Concentration Guides for specific radionuclides The sum of the ratios of those average concentrations to their respective DCGs was less than one fourth for all air and water sampling locations Applying the same methodology for reporting mixtures under the DCG concept as was used with RCGs, the measured concentrations in the tables have been compared to the concentration guides for specific radionuclides rather than to the guide for mixtures The fractions of ingested radionuclides that are absorbed in the gastro-intestinal tract and the lung clearance classes for inhaled radionuclides were chosen to yield the most restrictive DCGs for comparisons in this report Throughout this report, where a radionuclide concentration is expressed as the cumulative measurement of more than one isotope, the stated DCG used for comparison represents the most restrictive DCG for that grouping of isotopes Plutonium concentrations measured at Rocky Flats represent the alpha radioactivity from plutonium isotopes -239 and -240, which constitute over 97 percent of the alpha radioactivity in plutonium handled at the plant

Reported uranium concentrations are the cumulative alpha activity from uranium-233, -234, and -238 Components containing fully enriched uranium are handled at the Rocky Flats Plant Depleted uranium metal is fabricated and also is handled as a process waste material Uranium-235 is the major isotope by weight (93 percent) in fully enriched uranium, however, uranium-234 accounts for approximately 97 percent of the alpha activity of fully enriched uranium In depleted uranium, the combined alpha activity

from uranium-234 and -238 accounts for approximately 99 percent of the total alpha activity The uranium DCGs used in this report for air and water are those for uranium-233, -234, and uranium-238, which are the most restrictive

Environmental uranium concentrations can be measured by a variety of laboratory techniques Nonradiological techniques yield concentration units of mass per unit volume such as mg/m^3 and mg/l The uranium concentrations given in this report were derived by measuring radioactivity from alpha-emitting uranium isotopes and are expressed in terms of activity units per unit volume Rocky Flats data include measurements of depleted uranium, fully enriched uranium, and natural uranium

Conversion factors for specific types of uranium can be used to compare the data in this report to data from other facilities and agencies that are given in units of mass per unit volume, however, the resulting approximations will not have the same assurance of accuracy as that for the original measured values Uranium in effluent air from plant buildings is primarily depleted uranium The conversion factor for these data is $2\ 6 \times 10^6$ g/Ci Natural uranium is the predominant species found in water The conversion factor for water data is $1\ 5 \times 10^6$ g/Ci As an example, converting the 1988 mean concentration of uranium in water for Boulder Reservoir ($0\ 004 \times 10^{-9}$ µCi/ml) to concentration units of µg/ml would be done as follows

$$(0\ 004 \times 10^{-9}\ \mu Ci/ml)(1\ 5 \times 10^6\ g/Ci)(1 \times 10^{-6}\ Ci/\mu Ci)(1 \times 10^6\ \mu g/g) = 6 \times 10^{-6}\ \mu g/ml$$

The applicable EPA standard for beryllium (a nonradioactive material) in airborne effluents from plant buildings is 10 grams per stationary source in a 24-hour time period (US78) The calculated DCG in ambient air for plutonium-239 and -240 for members of the public is 20×10^{-15} µCi/ml ($7\ 4 \times 10^{-4}$ Bq/m^3)

The calculated americium-241 DCG in waterborne effluents for members of the public is 30×10^{-9} µCi/ml (1 1 Bq/l) The comparable DCG for plutonium-239, -240 in water is 30×10^{-9} µCi/ml (1 1 Bq/l) The most restrictive calculated DCG for uranium-233, -234, and -238 in water is 500×10^{-9} µCi/ml (19 Bq/l), which is the DCG for uranium -233 In waterborne effluents available to members of the public, the calculated DCG for tritium is $2{,}000{,}000 \times 10^{-9}$ µCi/ml (74,000 Bq/l)

In 1976, the EPA promulgated regulations for radionuclides in drinking water (US76a) These regulations were effective on June 24, 1977, along with primary drinking water regulations for microbiological, chemical, and physical contaminants The intent of the Safe Drinking Water Act was to ensure that each state has primary responsibility for maintaining drinking water quality To comply with these requirements, the Colorado State Board of Health modified existing State drinking water standards to include radionuclides (CO77, CO81) Two of the community drinking water

Appendix A
Applicable Guides and Standards

standards are of interest in this report The State standard for gross-alpha activity (including radium-226 but excluding radon and uranium) in community water systems is a maximum of 15 pCi/l or 15 X 10^{-9} µCi/ml (5 6 x 10^{-1} Bq/l) Americium and plutonium, which are alpha-emitting radionuclides, are included in this limit The limit for tritium in drinking water is 20,000 pCi/l or 20,000 x 10^{-9} µCi/ml (740 Bq/l)

The Rocky Flats Plant NPDES permit, which the EPA reissued in 1984 to DOE, established sanitary effluent limitations on discharges from Pond B-3 (treated sewage effluent), limitations for nitrate and pH in the discharge from Pond A-3 in the Walnut Creek drainage, limitations on discharge from the reverse osmosis pilot plant, on Woman Creek drainage, limitations on discharge from the reverse osmosis plant, and control of sediment release during discharge from Ponds A-4, B-5, and C-2

In addition to evaluating compliance with all applicable guides, limits, and standards, the Rocky Flats Plant Health , Safety and Environment Department assists operational groups in adhering to the DOE policy that " operations shall be conducted in a manner to assure that radiation exposure to individuals and population groups is limited to the lowest levels technically and economically practicable " (US81a)

Appendix A
Applicable Guides and Standards

TABLE A-1 Radiation Protection Standards for the Public
For Department of Energy Facilities (VA85)

	EFFECTIVE DOSE EQUIVALENT (mrem/year)
FROM ALL PATHWAYS	
OCCASIONAL EXPOSURES	500
PROLONGED EXPOSURES (> 5 years)	100

	DOSE EQUIVALENT (mrem/year)
INDIVIDUAL ORGAN	5,000

	DOSE EQUIVALENT (mrem/year)
AIR PATHWAY ONLY	
WHOLE BODY	25
ANY ORGAN	75

Appendix A
Applicable Guides and Standards

Table A-2 Applicable Guides for Radioactive and Nonradioactive Materials

Parameter	Applicable Guides and Standards	Reference
Airborne Effluents		
Plutonium-239,-240	NA	NA
Uranium-233,-234,-238	NA	NA
Tritium (H-3)	NA	NA
Beryllium	<10 0 g/day	40 CFR 61 32(a)
Ambient Air		
Plutonium-239,-240	20 0 X 10^{-15} µCi/ml	Calculated[a]
Waterborne Effluents		
Radioactive		
Plutonium-239,-240	30 x 10^{-9} µCi/ml	Calculated[a]
Uranium-233,-234,-238	500 x 10^{-9} µCi/ml	Calculated[a]
Americium-241	30 x 10^{-9} µCi/ml	Calculated[a]
Tritium (H-3)	2,000,000 x 10^{-9} µCi/ml	Calculated[a]

Discharge Limitations[b]

Parameter	Monthly Average	Weekly Average	Daily Maximum	Reference
Effluent Water Samples (Nonradioactive)				
pH		6 0-9 0 SU		NPDES Permit
Nitrates as N	10 mg/l	20 mg/l	NA	NPDES Permit
Total Phosphorus	8 mg/l	NA	12 mg/l	NPDES Permit
Biochemical Oxygen Demand, 5-Day	10 mg/l	NA	25 mg/l	NPDES Permit
Suspended Solids	30 mg/l	45 mg/l	NA	NPDES Permit
Total Chromium	0 05 mg/l	NA	0 1 mg/l	NPDES Permit
Residual Chlorine	NA	NA	0 5 mg/l	NPDES Permit
Oil and Grease	NA	NA	Visual	NPDES Permit
Fecal Coliform - No /100 ml	200	400	NA	NPDES Permit

a Derived Concentration Guides (DCGs) calculated on the basis of DOE February 1986 memorandum using DOE dose limit of 0 1 rem/yr to members of the public from all pathways dose conversion factors given in DOE/EH-0071, and intake rates of 2 66 X 10^{2} ml/s for air and 2 X 10^{3} ml/day for water (ST86)

b These limitations are presented as indicators of the types of parameters and associated concentration limits required by the NPDES permit Details of these requirements specific to each discharge location are given in the referenced document (US84a) The daily and monthly limitations indicated cannot be correlated with the annual water quality data summarized in Table 11

APPENDIX B
QUALITY CONTROL

A Quality Program Plan and a Quality Control Program Plan have been developed for the Environmental Management (EM) and the Health, Safety, and Environmental Analytical Laboratories (HS&E Laboratories) Sections, respectively Independent audits of these plans, coupled with EM's internal environmental audit and controls procedures, ensure that necessary quality assurance and quality control elements exist for a comprehensive environmental monitoring program

The Quality Program Plan developed by Environmental Management provides controls for assurance that

- Current charters exist for all environmental program elements that ensure all applicable requirements are satisfied in a comprehensive, integrated approach
- Current operating procedures exist for all phases of EM operations and that these procedures are implemented as written
- Appropriate approvals are obtained prior to significant program initiations or changes
- The equipment used in sample collection and data analysis is appropriate to the assigned function and is operating as required
- Accurate documentation exists for all programs, procedures, actions, and audits
- All variances from procedures or equipment use and performance are documented and explained with an assessment
- Appropriate guidelines and standards for environmental monitoring are identified, and documentation of compliance is provided on a routine basis to Rocky Flats Plant management, Department of Energy (DOE), and state and federal regulatory agencies

The EM Quality Program Plan establishes control points and delineates responsibilities for specific categories of activities, provides an information base from which procedures can be developed, updated, and/or implemented, establishes a state of emergency preparedness in its contingency plans, and provides documentation to comply with rules and regulations of federal, state, and local regulatory agencies

The Plan includes quality assurance flow charts and quality matrices that illustrate activity networks and corresponding quality elements of each responsibility area A complete listing of activities and responsibilities is also included in the Plan

APPENDIX B. QUALITY CONTROL

To ensure data reliability, the HS&E Laboratories Quality Control Program Plan outlines its quality control methods used in all phases of laboratory operations

This laboratory quality control program includes the following elements

- Development, evaluation, improvement, modification, and documentation of analytical procedures
- Scheduled instrument calibration, control charting, and preventive maintenance
- Participation in interlaboratory quality comparison programs
- Intralaboratory quality control programs

All sample batches scheduled for analysis by the HS&E Laboratories Central Receiving Laboratory contain an average of 10 percent control samples The controls consist of analytical blanks prepared in-house and standards prepared by the Rocky Flats Plant Chemistry Standards Laboratory

An analysis or group of analyses may be rejected and the sample or samples scheduled for reanalysis for one or more of the following reasons

1 The chemical recovery is less than 10 percent or greater than 100 percent

2 The analytical blanks in the analysis batch are out of acceptable range

3 The standards in the analysis batch are not within acceptable limits of error

4 The alpha energy spectrum is not acceptable because of the following

   a extra and/or unidentified peaks
   b excess noise in background areas
   c poor resolution of peaks

5 The chemist in charge of the laboratory believes there is reason to suspect the analysis

Any unusual condition affecting the results, which is noted either during sample collection or analysis, is reported to Environmental Management

Table B-1 is a summary of HS&E Laboratories participation in the Rocky Flats Plant Interactive Measurement Evaluation and Control System for 1988

The HS&E Laboratories participates in the EPA Environmental Monitoring Systems Laboratory (EMSL) and the DOE Environmental Measurements Laboratory Crosscheck Programs Tables B-2 and B-3 summarize the HS&E Laboratories participation in these programs

TABLE B-1 Health, Safety and Environmental Laboratories Interactive Measurement Evaluation and Control System (January through December 1988)

Attribute	Matrix	Method	Standard Range		Normal Sample Range		Annual Relative Error Percent[a]	Range of Relative Error Percent	Total Control Analyses
Pu 239 -240	Water	Alpha Spectral	1 2-35	d/m/l[b]	0-3	d/m/l	-73	-100 to - 49	56
Am 241	Water	Alpha Spectral	0 7-21	d/m/l	0-3	d/m/l	-56	- 99 to +19	55
U 238 -234 -235	Water	Alpha Spectral	3-90	d/m/l	0-30	d/m/l	-46	-100 to +20	56
H 3	Water	Liquid Scintillation	5,000-60,000	d/m/l	0-9,990	d/m/l	-24	-84 to +114	52
Pu 239, 240	Effluent Filters	Alpha Spectral	4-120	d/m/f[b]	0-30	d/m/f	+6	-97 to +635	115
Am 241	Effluent Filters	Alpha Spectral	3-90	d/m/f	0-4	d/m/f	-5	-100 to +20	109
U 238, -234, -235	Effluent Filters	Alpha Spectral	10-300	d/m/f	0-30	d/m/f	-25	-100 to +14	115
Be[c]	Effluent Filters	Atomic Absorption	0 3 -10	µg/f[b]	0-5	µg/f	-6	-100 to +136	120
Be	Workplace Filters	Atomic Absorption	0 3-10	µg/f	0 20	µg/f	-7	-94 to +197	1,132
Pu 239 -240	Ambient Filters	Alpha Spectral	2-45	d/m/f	0-50	d/m/f	-3	-48 to +243	52

a The mean of the ratio of the 12 month differences between observed and standard values to the standard values in percent. This term is inclusive of all random and systematic error in the standards, analytical chemistry and measurement process for a given nuclide, matrix, and procedure

b d/m/l = disintegrations per minute per liter; d/m/f = disintegrations per minute per filter, µg/f = micrograms per filter

c Analyzed by 881 General Laboratory

87

APPENDIX B. QUALITY CONTROL

TABLE B-2 Health, Safety and Environmental Laboratories Participation in the EPA Environmental Monitoring Systems Laboratory Crosscheck Program During 1988

Isotope Reported	Matrix	Method	Number of Analyses	Number of Acceptable Analyses[a]	Annual Relative Error Percent[b]	Range of Relative Error Percent
Gross Alpha	Filter	Alpha Spectral	1	1	-13 3	NA[c]
Gross Beta	Filter	Gas Proportional	1	1	- 4 7	NA[c]
H-3	Water	Beta Liquid Scintillation	3	2	15 8	-16 0 to 79 0
Co - 60	Water	Gamma Spectral	4	4	- 1 7	- 7 7 to 13 3
Cs - 134	Water	Gamma Spectral	3	2	-15 6	-26 6 to 8 0
Cs - 137	Water	Gamma Spectral	4	4	7 3	0 7 to 26 6
Cr-51	Water	Gamma Spectral	2	2	2 6	1 4 to 3 6
Ru - 106	Water	Gamma Spectral	3	2	-26 3	-30 9 to -10 0
Pu - 239	Water	Alpha Spectral	1	1	- 2 0	NA[c]
U (nat)	Water	Alpha Spectral	3	3	- 2 3	-11 2 to 11 0

a "Acceptable analyses" are those analyses for which the observed value was within ± 3 standard deviations of the standard value

b The mean of the ratio of the12-month differences between observed and standard values to standard values in percent This term is inclusive of all random and systematic error in the standards, analytical chemistry, and measurement process for a given nuclide matrix and procedure

c NA = Not applicable

TABLE B-3 Health, Safety and Environmental Laboratories Participation in the DOE Environmental Monitoring Systems Laboratory Crosscheck Program During 1988

Isotope Reported	Matrix	Method	Number of Analyses	Mean of Ratio Reported/Standard Value	Range of Ratios
Mn - 54	Water	Gamma Spectral	1	1 13	NA[a]
Co - 60	Water	Gamma Spectral	1	1 05	NA[a]
Cs-134	Water	Gamma Spectral	1	1 07	NA[a]
Cs - 137	Water	Gamma Spectral	1	1 14	NA[a]
Pu - 239	Soil	Alpha Spectral	1	1 61	NA[a]
U (nat)	Soil	Alpha Spectral	1	0 85	NA[a]
Co-59	Water	Gamma Spectral	1	1 16	NA[a]

a Not Applicable

APPENDIX C
ANALYTICAL PROCEDURES

The Health, Safety and Environmental Laboratories (HS&E Laboratories) routinely perform the following analyses on environmental and effluent samples

1 Total Air Filter Counting
(Pu specific alpha)
2 Gas Proportional Counting
(Gross alpha & gross beta)
3 Gamma Spectral Analysis
4 Alpha Spectral Analysis
(Pu-239, -238, Am-241,
U-238, -233, -234)
5 Beta Liquid Scintillation (Tritium)
6 N,N-Diethyl-p-phenylenediamine
(DPD) (Chlorine)
7 Atomic Absorption (Beryllium)
8 Millipore Filtration Method
(Fecal and Total Coliform)

Procedures for these analyses are described in the HS&E Laboratories Procedures and Practices Manual (WI82) The procedures for bacteria and chlorine analyses were developed following Environmental Protection Agency (EPA) guidelines Soil procedures were developed following specifications set forth in "Measurements of Radionuclides in the Environment, Sampling and Analysis of Plutonium in Soil," NRC Reg Guide 4 5 All new procedures and changes to existing procedures must be thoroughly tested, documented, and approved in writing by the Manager of HS&E Laboratories before being implemented Environmental Management is notified of any major changes that could affect analytical results All procedures are reviewed annually for consistency with state-of-the-art techniques, or at any time an analytical problem is suspected Copies of all procedures are kept on file in the office of the Manager of HS&E Laboratories

The following is a general outline of the analytical procedures followed by the laboratories

Samples received for air filter screening are counted at approximately 24 and then 48 hours after collection Samples exceeding the limits set by Environmental Management are recounted If the total long-lived alpha concentration for a screened filter exceeds the EM action limits, the filter is directed for individual specific isotope analysis and/or followup investigation to determine the cause and any needed corrective action

All water samples, except those scheduled for tritium analysis, are poured into one-liter Marinelli containers and sealed before delivery to the gamma counting area Routine water samples are counted for approximately twelve hours Samples requiring a lower detection limit are counted from 16 to 72 hours

Soil samples scheduled for gamma spectral analysis are dried, sieved through a ten-mesh sieve, weighed, and the fine portion is ball-milled The fine portion is then placed in a 500-ml Marinelli container and counted for at least 16 hours

Appendix C. Analytical Procedures

All samples scheduled for alpha spectral analysis are analyzed in a similar manner regardless of matrix Prior to dissolution, a known quantity of nonindigenous radioactive tracer is added to each sample The tracer is used to determine the chemical recovery for the analysis Tracers used include Pu-236, Pu-242, U-232, U-236, Am-243, and Cm-244 The type and activity level of the tracer used depends on the type and projected activity level of the sample to be analyzed All refractory or intractable actinides are dissolved by vigorous acid treatment using oxidizing and complexing acids

After samples are dissolved, the radioisotopes of concern are separated from each other and from the matrix material by various solvent extraction and ion exchange techniques The purified radioisotopes are electrodeposited onto stainless steel discs These discs are alpha counted for 12 hours If a lower minimum detection limit is required, samples may be counted from 72 to 168 hours depending on the need Samples that exhibit a chemical recovery of less than 10 percent or greater than 110 percent are automatically scheduled for reanalysis

Tritium analyses are routinely performed on specified environmental water samples as well as stack effluent samples Five milliliters of the samples are combined with 15 milliliters of liquid scintillation fluid Environmental samples generally are counted for 120 minutes and airborne effluent samples generally are counted for 10 minutes

The General Laboratory routinely performs the following analyses for environmental monitoring of plant effluent streams, process wastes, and soil residues

1 Dissolved metallic elements including tests for 19 cations by Inductively Coupled Plasma Spectrascopic (ICP) techniques and 17 elements by atomic absorption techniques (including beryllium in airborne effluent sample filters)

2 Oxygen demand tests, including total organic carbon, dissolved oxygen, chemical oxygen demand, and biological oxygen demand (5 day incubation)

3 Nutrient tests including free ammonia, ortho and total phosphate phosphorus, nitrite and nitrate anions

4 Physical tests, including pH, conductivity, color, total dissolved solids, suspended solids, turbidity, and specific gravity

5 Soap residues (as alkyl sulfonate)

6 Oil and grease residues, by extraction and infrared or gravimetric detection, and by visual observation

7 Specific chemical property or element, including total hardness (as calcium carbonate), alkalinity (as hydroxide, bicarbonate, or carbonate), chloride, fluoride, cyanide, sulfate, and hexavalent chromium

8 Radioactive species, including gross alpha and beta by gas proportional detection, tritium by

liquid scintillation detection, total radiostrontium by gravimetric separation followed by gas proportional detection Isotopes of plutonium, americium, and uranium are determined by ion exchange and liquid extraction techniques followed by alpha pulse height analysis

9 Polychlorinated biphenyl and volatile and semivolatile compounds from the EPA Contract Laboratory Program (EPA-CLP) Target Compound List are analyzed by gas chromatography/mass spectrography Phenols also are analyzed using spectrophotometry

Procedures for these analyses were developed by the General Laboratory analytical technical staff Procedures were adopted from EPA-approved sources or from other recognized authoritative publications where EPA-approved procedures were not available Laboratory operations procedures are documented in a standard format, approved by the manager of the Rocky Flats Analytical Laboratories, and distributed to a controlled distribution list to assure that proper testing and approval is performed before changes are adopted The General Laboratory Quality Assurance Plan requires annual review of procedures for consistency with state-of-the-art techniques and compliance of laboratory practice with written procedures In addition, a review is performed whenever an analytical problem is indicated

The following is a general outline of the analytical procedures followed by the General Laboratory

All water samples which are analyzed for radioactive materials - except those scheduled for tritium analysis - are acidified immediately upon collection

Liquid samples received for gross alpha and beta screening are evaporated directly onto planchets for gas proportional counting When activities exceeding the action guidelines set by Environmental Management (EM) are observed, notification to EM is made, and reanalysis and/or investigation may be required

For some liquids such as machine oils, a specified volume is evaporated, ashed, and the salt residue is taken up in nitric acid for deposition onto the counting planchet. A correction factor is determined for each sample to account for self-absorption effects

Water samples to be tested for chemical and physical parameters are analyzed within 24 hours of collection, or they are preserved by refrigeration, freezing, or addition of a chemical preservative when required The tests performed include gravimetric, titrametric, colorimetric, chromatographic, or electroanalytical methods, following procedures specified in the 16th edition of *Standard Methods for the Examination of Water and Waste Water, Methods for Chemical Analysis of Water and Wastes*, or other authoritative publications

Water samples to be analyzed for dissolved metallic ions are filtered through a 0 45 micrometer filter, preserved with nitric acid and digested before being analyzed by atomic absorption or ICP methods

Organic toxic species are determined by chromatography, using electron capture detection Some organics, such as phenol, are determined by developing a chro-

maphoric complex and measuring light absorption at a specific wave-length with a spectrophotometer Measuring occurs after extraction into an appropriate solvent phase

Tritium is measured using liquid scintillation counting Counting efficiency is determined using a separately - prepared sample to which is added a known standard tritium activity

Strontium is radiochemically separated from the sample matrix using precipitation techniques Strontium is deposited on planchets with a carrier element and the activity in the sample is quantified using beta gas proportional counting

APPENDIX D
DETECTION LIMITS AND ERROR TERM PROPAGATION

The Rocky Flats Health, Safety and Environmental Laboratories (HS&E Laboratories) have adopted the following definition for detection limit, as given by Harley (HA72)

"The smallest amount of sample activity using a given measurement process (i e chemical procedure and detector) that will yield a net count for which there is confidence at a pre- determined level that activity is present "

The minimum detectable amount (MDA) is the term used to describe the detection limit and is defined as the smallest amount of an analyzed material in a sample that will be detected with a β probability of non-detection (Type II error), while accepting an α probability of erroneously detecting that material in an appropriate blank sample (Type I error) At the 95% confidence level, both α and β are equal to 0 05

Based on the approach presented in draft ANSI standard N13 30 "Performance Criteria for Radiobioassay,"(HE85) the formulation of the MDA for radioactive analyses is

$$MDA = \frac{4.65\, S_B + 3/(T_S E_S Y)}{aV}$$

where S_B = standard deviation of the population of appropriate blank values (disintegrations per minute, d/m)

T_S = sample count time (minutes, m)

E_S = absolute detection efficiency of the sample detector

Y = chemical recovery for the sample

a = conversion factor (disintegrations per minute per unit activity)

(a = 2 22 d/m/pCi when MDA is in units of pCi and a = 2 22 X 10^6 d/m/μCi when MDA is in units of μCi)

V = sample volume or weight (V=1 if the MDA per sample is desired)

The major component of the MDA equation is the variability of the blanks

Table D-1 shows the various formulae used for alpha data reduction during 1988

Appendix D. Detection Limits and Error Term Propagation

Table D-2 shows the typical MDA values for the various analyses performed by the HS&E Laboratories and by the General Laboratories These values are based on the average sample volume, typical detector efficiency, detector background, count time, and chemical recovery MDA values calculated for individual analyses may vary significantly depending on actual sample volume, chemical recovery, and analytical blank used

For nonradioactive parameters, various means are used to estimate a minimum detectable amount depending on the parameter measured The minimum detectable amount for beryllium in effluent air - analyzed using flameless atomic absorption spectroscopy - is based on a sample blank absorbance reading Total chromium in effluent water samples undergoes a fourfold concentration of the received sample prior to its analysis using flame atomic absorption spectroscopy Its approximate minimum detectable amount is based on a net sample absorbance reading of 0 010

The parameters of nitrate as N, total phosphorous, suspended solids, oil and grease, and total organic carbon all have minimum detectable amounts that are determined by procedural methods found in EPA-600, *Methods for Chemical Analysis of Water and Wastewater* (US87c) The parameters of pH and biochemical oxygen demand have minimum detectable amounts that are determined by the minimal readout capability of the instrumentation that is used

The minimum detectable amount for residual chlorine is determined by the procedure found in a publication by Hach Co , "DPD Method for Chlorine "(HA83) For fecal coliform count, the minimum detectable amount is calculated as 4 65 times the standard deviation of the blank value from the millipore filter

Appendix D. Detection Limits and Error Term Propagation

Table D-1 Formulae for Activity and Uncertainty Calculations for the Alpha Spectral Analysis Systems

Non-Blank Corrected Sample Activity

$$A_{SI} = \left[\frac{\frac{C_{SI}}{T_S} - \frac{C_{BI}}{T_B}}{\frac{C_{SJ}}{T_S} - \frac{C_{BJ}}{T_B}} \right] \frac{D_{SJ}}{V \; 2.22}$$

Blank Corrected Sample Activity

$$B_{SI} = A_{SI} - A_{rI}$$

Non-Blank Corrected Sample Uncertainty*

$$a_{SI} = A_{SI} \left[\frac{\frac{C_{SI}}{T_S^2} + \frac{C_{BI}}{T_B^2}}{\left(\frac{C_{SI}}{T_S} - \frac{C_{BI}}{T_B} \right)^2} + \frac{\frac{C_{SJ}}{T_S^2} + \frac{C_{BJ}}{T_B^2}}{\left(\frac{C_{SJ}}{T_S} - \frac{C_{BJ}}{T_B} \right)^2} \right]^{1/2}$$

Blank Corrected Sample Uncertainty

$$b_{SI} = \left(a_{SI}^2 + a_{rI}^2 \right)^{1/2}$$

*Corrected from 1984 report

LEGEND

A_{rI}	=	Non-blank corrected activity of laboratory reagent blank for isotope i expressed as picocuries (pCi) per unit volume
a_{rI}	=	Non-blank corrected uncertainty of laboratory reagent blank expressed as pCi per unit volume
A_{SI}	=	Sample activity for isotope i expressed as pCi per unit volume
a_{SI}	=	Sample activity uncertainty expressed as pCi per unit volume
B_{SI}	=	Blank corrected sample activity for isotope i expressed as pCi per unit volume
b_{SI}	=	Blank corrected sample uncertainty expressed as pCi per unit volume
D_{SJ}	=	Activity (dpm) of internal standard isotope j added to sample
C_{SI}	=	Sample gross counts for isotope i
C_{SJ}	=	Sample gross counts for internal standard isotope j
C_{BI}	=	Detector background gross counts for isotope i
C_{BJ}	=	Detector background gross counts for internal standard isotope j
T_S	=	Sample count time expressed in minutes
T_B	=	Detector background count time expressed in minutes
V	=	Sample unit volume or sample unit weight

Appendix D. Detection Limits and Error Term Propagation

TABLE D-2 Detection Limits for Radioactive and Nonradioactive Materials

Parameter	Minimum Detectable Amount (per sample)	Approximate Sample Volume Analyzed[a]	Minimum Detectable Amount (per unit volume or mass)
Airborne Effluent Samples			
Plutonium -239, -240	3.8×10^{-7} µCi	7,340 m^3 [b]	0.05×10^{-15} µCi/ml
Uranium -233, -234, -238	5.7×10^{-7} µCi	7,340 m^3 [b]	0.08×10^{-15} µCi/ml
Americium -241	1.8×10^{-7} µCi	7,340 m^3 [b]	0.02×10^{-15} µCi/ml
Tritium (H-3)	4.8×10^{-6} µCi	1.4 m^3	$3{,}400 \times 10^{-15}$ µCi/ml
Beryllium	2.5×10^{-1} µg	7,340 m^3 [b]	3×10^{-5} µg/m^3
Ambient Air Samples			
Plutonium -239, -240	1.2×10^{-7} µCi	29,000 m^3 [c]	0.004×10^{-15} µCi/ml
Effluent Water Samples (Radioactive)			
Plutonium -239, -240	9.2×10^{-8} µCi	5,000 ml	0.02×10^{-9} µCi/ml[c]
Uranium -233, -234, -238	2.9×10^{-7} µCi	1,000 ml	0.29×10^{-9} µCi/ml
Americium -241	1.5×10^{-7} µCi	5,000 ml	0.03×10^{-9} µCi/ml[c]
Tritium (H-3)	2.5×10^{-6} µCi	5 ml	500×10^{-9} µCi/ml
Soil Samples (Radioactive)			
Plutonium -239, -240	8.4×10^{-8} µCi	10 g	8.4×10^{-9} µCi/g
Effluent Water Samples (Nonradioactive)			
pH		100 ml	0-14 SU
Nitrate as N		4 ml	0.02 mg/l
Total Phosphorus		50 ml	0.2 mg/l
Biochemical Oxygen Demand, 5-Day		300 ml	5.0 mg/l
Suspended Solids		100 ml	1.0 mg/l
Total Chromium		100 ml	0.05 mg/l
Residual Chlorine		10 ml	0.1 mg/l
Oil and Grease		1,000 ml	0.5 mg/l
Fecal Coliform Count		10-100 ml	43 organisms/100 ml
Total Organic Carbon		5 ml	1.0 mg/l

a *Volume analyzed* is usually an aliquoted fraction of the total sample volume collected
b Monthly composite
c Composite of two bi-weekly samples

APPENDIX E
REPORTING OF MINIMUM DETECTABLE CONCENTRATION AND ERROR TERMS

Throughout the section entitled "Monitoring Data Collection, Analyses, and Evaluation" in this report, some of the concentrations that are measured at or below the minimum detectable concentration (MDC) are assigned the MDC value The less-than symbol (<) indicates MDC values and calculated values that include one or more MDCs

The plutonium, uranium, americium, and beryllium measured concentrations are reported These reported concentrations include values that are less than the corresponding calculated MDCs and in some cases, values less than zero Negative values result when the measured value for a laboratory reagent blank is subtracted from an analytical result that was measured as a smaller value than the reagent blank These resulting negative values are included in any arithmetic calculations on the data set

Error terms in the form of a $\pm$ b are included with some of the data For a single sample, "a" is the reagent-blank corrected value, for multiple samples it represents the average value (arithmetic mean) The error term "b" accounts for the propagated statistical counting uncertainty for the sample and the associated reagent blanks at the 95 percent confidence level These error terms represent a minimum estimate of error for the data

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GLOSSARY

activity See radioactivity

alpha particle A positively charged particle emitted from the nucleus of an atom having the same charge and mass as that of a helium nucleus (2 protons, 2 neutrons)

atom Smallest particle of an element capable of entering into a chemical reaction

beta particle A negatively charged particle emitted from the nucleus of an atom having a mass and charge equal to that of an electron

contamination The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or personnel

concentration The amount of a specified substance or amount of radioactivity in a given volume or mass

cosmic radiation Radiation of many types with very high energies, originating outside the earth's atmosphere Cosmic radiation is one source contributing to natural background radiation

curie (Ci) The traditional unit for measurement of radioactivity based on the rate of radioactive disintegration One curie is defined as 3.7×10^{10} (37 billion) disintegrations per second Several fractions and multiples of the curie are in common usage

millicurie (mCi) -10^{-3} Ci, one-thousandth of a curie, 3.7×10^{7} disintegrations per second

microcurie (μCi) -10^{-6} Ci, one-millionth of a curie, 3.7×10^{4} disintegrations per second

nanocurie (nCi) -10^{-9} Ci, ,one-billionth of a curie, 37 disintegrations per second

picocurie (pCi) -10^{-12}, one-trillionth of a curie, 0 037 disintegrations per second

femtocurie (fCi) -10^{-15} Ci, one-quadrillionth of a curie, 0 000037 disintegrations per second

attocurie (aCi) 10^{-18} Ci, one-quintillionth of a curie, 0 000000037 disintegrations per second

decay, radioactive The spontaneous transformation of one radionuclide into a different radioactive or nonradioactive nuclide, or into a different energy state of the same radionuclide

Derived Concentration Guide (DCG) Secondary radioactivity in air and water concentration guides used for comparison to measured radioactivity concentrations Calculation of DCGs assumes that the exposed individual inhales 8,400 cubic meters of air per year or ingests 730 liters of water per year at the specified radioactivity DCG with a resulting radiation dose of 0 1 rem effective dose equivalent

disintegration, nuclear A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus of an atom

dose, absorbed The amount of energy deposited by radiation in a given mass of material The unit of absorbed dose is the rad or the Gray (1 Gray = 100 rad)

Glossary

dose commitment The total radiation dose projected to be received from an exposure to radiation or intake of radioactive material throughout the specified remaining lifetime of an individual In theoretical calculations, this specified lifetime is usually assumed to be 50 years

dose equivalent A modification to absorbed dose which expresses the biological effects of all types of radiation (e g , alpha, beta, gamma) on a common scale The unit of dose equivalent is the rem or the sievert (1 sievert = 100 rem)

exposure A measure of the ionization produced in air by x- or gamma radiation The special unit of exposure is the Roentgen (R)

gamma ray High-energy, short-wavelength electromagnetic radiation emitted from the nucleus of an atom Gamma radiation frequently accompanies the emission of alpha or beta particles Gamma rays are identical to x-rays except for the source of the emission

half-life, radioactive The time required for a given amount of a radionuclide to lose half of its activity by radioactive decay Each radionuclide has a unique half-life

isotopes Forms of an element having the same number of protons in their nuclei and differing in the number of neutrons

minimum detectable concentration (MDC) The smallest amount or concentration of a radio-element that can be distinguished in a sample by a given measurement system in a preselected counting time at a given confidence level

natural radiation Radiation arising from cosmic sources and from naturally occurring radionuclides (such as radon) present in the human environment

outfall The place when a storm sewer or effluent line discharges to the environment.

part per billion (ppb) Concentration unit approximately equivalent to µg/l

part per million (ppm) Concentration unit approximately equivalent to mg/l

person-rem The tradiational unit of collective dose to a population group For example, a dose of one rem to 10 individuals results in a collective dose of 10 person-rem

quality factor The factor by which the absorbed dose (in rad or gray) is multiplied to obtain the dose equivalent (in rem or sievert) The dose equivalent is a unit that expresses, on a common scale for all ionizing radiation, the biological damage to exposed persons It is used because some types of radiation, such as alpha particles, are more biologically damaging than others.

rad A traditional unit of absorbed dose The International System of Units (S I) unit of absorbed dose is the gray (One gray = 100 rads)

radioactivity The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the unstable nucleus of an atom

radionuclide An atom having an unstable ratio of neutrons to protons so that it will tend toward stability by undergoing radioactive decay A radioactive nuclide

rem The traditional unit of dose equivalent Dose equivalent is frequently reported in units of millirem (mrem) which is one-thousandth of a rem The International System of Units (S I) unit of dose equivalent is the sievert (one sievert = 100 rem)

roentgen (R) The traditional unit of exposure to X- or gamma radiation based on the ionization in air caused by the radiation One roentgen is equal to 2.58 X 10^{-4} coulombs per kilogram of air A common expression of radiation exposure is the milliroentgen (1R = 1000 mR)

sievert (Sv) International System of Units (S I) Unit for radiation dose, 1 Sv = 100 rem

thermoluminescent dosimeter (TLD) A device used to measure external sources (i e , outside the body) of penetrating radiation such as X-rays or gamma rays

tritium (H-3). The hydrogen isotope having one proton and two neutrons in the nucleus It is radioactive and emits a low energy beta particle (0 0186 MeV max)

uncontrolled area Any area to which access is not controlled for the purpose of protecting individuals from exposure to radiation and radioactive materials. The area beyond the boundary of the Rocky Flats Plant is an uncontrolled area

worldwide fallout Radioactive debris from atmospheric weapons tests that is either airborne and cycling around the earth or has been deposited on the earth's surface

TRADITIONAL AND INTERNATIONAL SYSTEM OF RADIOLOGICAL UNITS

(Traditional units are in parentheses)

Quantity	Name	Symbol	Expression in Terms of Other Units
absorbed dose	gray	Gy	Jkg^{-1}
	(rad)	rad	10^{-2} Gy
activity	bequerel	Bq	1 dps
	(curie)	Ci	3.7×10^{10} Bq
dose equivalent	sievert	Sv	Jkg^{-1}
	(rem)	rem	10^{-2} Sv
exposure	coulomb per kilogram		Ckg^{-1}
	(roentgen)	R	2.58×10^{-4} Ckg^{-1}